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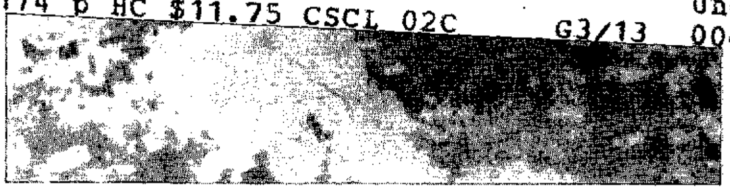

Evaluation and Comparison of ERTS Measurements of Major Crops and Soil Associations for Selected Test Sites in the Central United States

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16. Abstract

Multispectral scanner data obtained by ERTS-1 over six test sites in the Central United States were analyzed and interpreted. ERTS-1 data for some of the test sites were geometrically corrected and temporally overlayed. Computer-implemented pattern recognition techniques were used in the analysis of all multispectral data. These techniques were used to evaluate ERTS-1 data as a tool for soil survey. Geology maps and land use inventories were prepared by digital analysis of multispectral data. Identification and mapping of crop species and rangelands were achieved through the analysis of 1972 and 1973 ERTS data. Multiple dates of ERTS data were examined to determine the variation with time of the areal extent of surface water resources on the Southern Great Plains.

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Cover Photo: ERTS data collected 22 October 1973 (Band 7 0.80-1.10μm, Scene ID 1456-16504) showing part of the Lubbock Regional Test Site. Light areas are agricultural areas of the Southern High Plains. Dark areas are predominantly rangeland.

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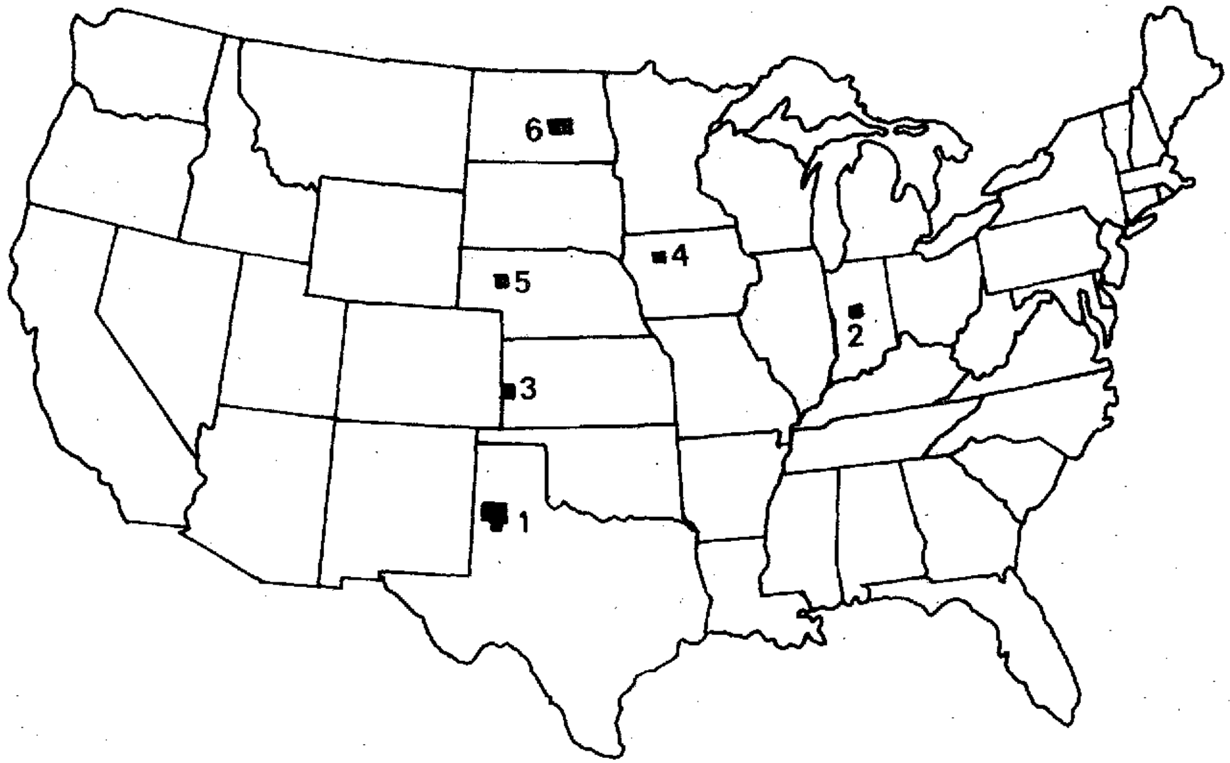
I. OBJECTIVES

The objectives of the research reported herein are outlined in the Data Analysis Plan for the investigation "Evaluation and Comparison of ERTS Measurements of Major Crops and Soil Associations for Selected Sites in the Central United States," ERTS-1 Proposal Number SR050. The broad objective of the proposal is to evaluate the utility of ERTS-1 measurements for use in identifying, locating, characterizing and mapping differences in vegetation and soils over a wide range of climatic, geographical, and ecological conditions in the Central United States.

II. SCOPE OF WORK

ERTS measurements were obtained over six widely separated test sites (Figure 1). These include (1) Lubbock, Texas Regional Test Site, (2) Boone and Hendricks Counties, Indiana, (3) Greeley County, Kansas, (4) Humboldt County, Iowa, (5) McPherson County, Nebraska, and (5) Wells County, North Dakota. Fifty-six ground observation sites, each of approximately 10 kilometers in length, have been designated for the Lubbock Regional Test Site. A limited amount of color and color infrared photography was available for all test sites as ground information. Observations of agricultural significance have been collected for the 1972 and 1973 growing season. Digital computer techniques (the LARS software system) were used in the analysis of all ERTS-1 data.



1	Lubbock, Texas Regional Test Site	4	Humboldt County, Iowa
2	Boone and Hendricks Counties, Indiana	5	McPherson County, Nebraska
3	Greeley County, Kansas	6	Wells County, North Dakota

Figure 1. Geographical Location of Test Sites in the Central United States.

III. RESULTS

A. LUBBOCK REGIONAL TEST SITE ANALYSIS

1. CROSBY COUNTY, TEXAS SOIL STUDY

Crosby County, Texas lies in the Southern High Plains in west-central Texas. Two thirds of the county is a level plain, a part of the Llano Estacado bissected by Blanco Canyon. The rest of the county lies in the rough, dissected Rolling Plains or Osage physiographic subsection. The Osage subsection is separated from the High Plains by the rim of the Caprock Escarpment. Crosby County is dotted with shallow depressions called playas or lakes in the Llano Estacado region.

The playas or lakes consist of Pliocene deposits of bentonitic clays and sand. Unconsolidated clays, sands and gravels of the Ogallala group are the chief underlying materials. Most playas become intermittent lakes after high intensity or short heavy rains.

The soils of the Llano Estacado and the High Plains in the northern and northeastern parts of the county are classified as Pullman association (deep hard land). These soils are dark in color and are well supplied with bases. The surface layer is brown to dark grayish-brown silty clay loam. These soils are hard when dry and friable when moist.

The soils of the west central part of the county, south of the Lorenzo-Ralls-Crosbyton line belong to the Olton (mixed land), Amarillo, and Amarillo-Brownfield associations (sandy lands).

The well-drained Olton soils are reddish-brown to dark brown loam or clay loam; however, the Olton contains less clay than the Pullman soils. Amarillo soils are well-drained, reddish-brown soils which occupy the southwestern part of the county. They are fine sandy loams and have a high moisture-supplying capacity, suitable for irrigation purposes. Brownfield soils, found in the same area, are light-colored sandy soils. They have a thicker, more sandy surface layer than that of the Amarillo soils and are highly susceptible to wind erosion. Most of this acreage is in rangeland.

The Rolling Plains region or Ogallala formation consists of fluviatile sand, silt, and clay and gravel and underlies the High Plains portion of the county. It is exposed only in Blanco Canyon and at or near the Caprock Escarpment. The region below the Caprock Escarpment contains extensive "badlands" topography.

The Berthoud-Mansker-Potter soil association is found on the foot slopes below the Caprock Escarpment. They are

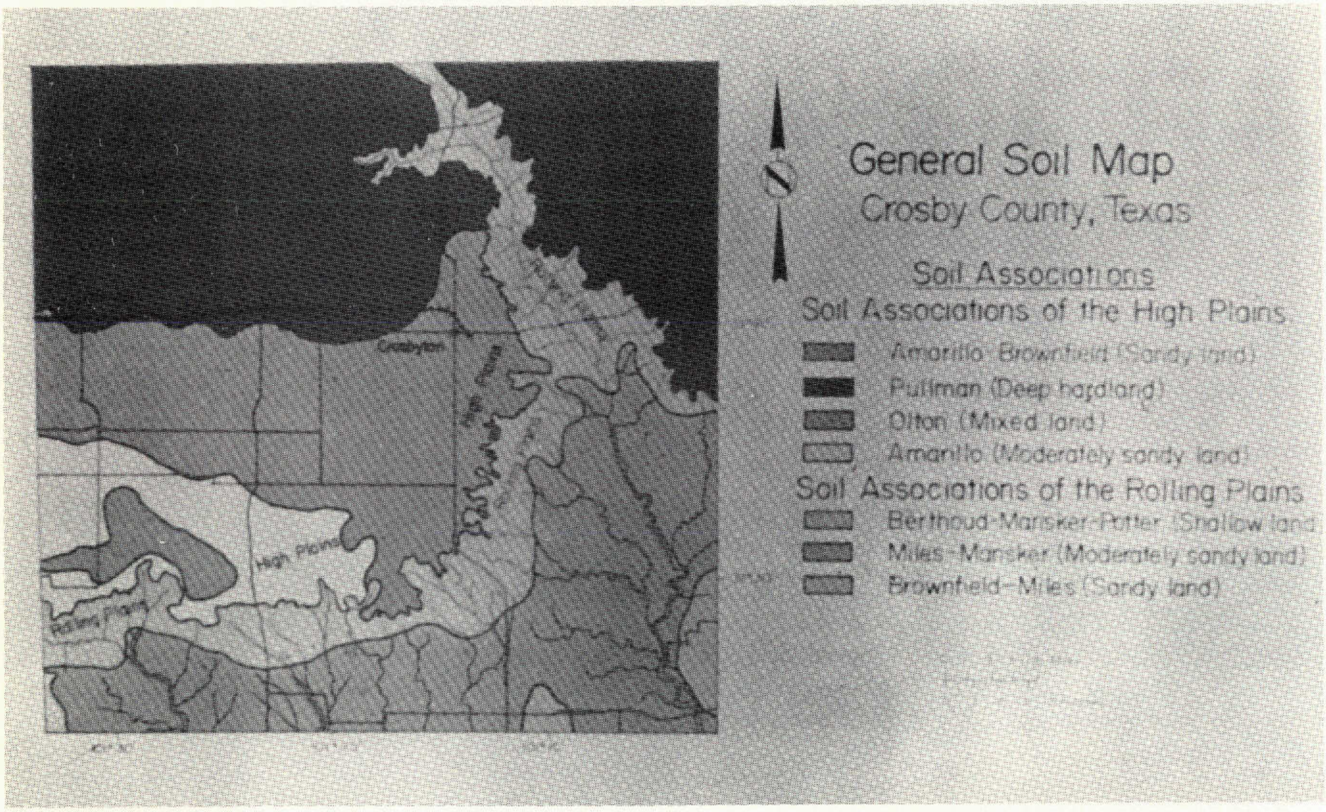


Figure 2. Soil association map of Crosby County, Texas.

calcareous, well-drained shallow soils which are poorly suited for cultivation. Almost all of their acreage is utilized as rangeland. Representatives of this association occur throughout the county.

The southern and eastern part of the Rolling Plains is moderately sandy. These soils (Miles-Mansker association) are brown to reddish sandy loams. They are very hard when dry but very friable when moist.

The soils of the sand dunes area of Crosby County, which lie chiefly along the southern border of the county, belong to the Brownfield-Miles association. The soil surface layer is very pale brown to brown fine sand. The geologic materials from which these soils are formed are chiefly water-deposited sands that were subsequently resorted by wind action. A few areas of the dunes are cultivated and are used for supplemental feed crops.

The climate of the county is dry; however, hail and drought are commonplace events. Most of the area below the Caprock Escarpment is drained by the White and Brazos Rivers and their tributaries. The populace engages mostly in livestock raising and growing of winter wheat, grain sorghum and cotton, using irrigation methods.

a. <u>Procedure</u>

The capability of the ERTS program to obtain data over the same geographic area every 18 days provides the opportunity to analyze seasonal changes of certain geographic regions. Registration of multitemporal and geometrically corrected data, techniques recently developed at LARS, makes a big contribution in the further improvement of soil pattern identification. With this new approach, four frames of data: 9 October 1972 (Scene ID 1078-16524), 14 November 1972 (Scene ID 1114-16532), 2 December 1972 (Scene ID 1132-16532), and 18 June 1973 (Scene ID 1366-16521) were used for analysis. False color images of the investigated area on four different dates were observed. The color composites were made from bands 0.5-0.6μm, 0.6-0.7μm and 0.8-1.10μm. These images have provided correct information on soil associations in Crosby County, an area of 2360 km^2. The soil association map (1:190,080 scale) of the county was used to overlay the ERTS color imagery of approximately the same scale.

A digital image display system has been used to display the images in a raster scanning mode on a standard television screen. With the light pen a set of samples of each soil association was selected from the December data. These sets served as training sets for computer-implemented analysis. For every training set and for every sample within the set, the

LARSYS STATISTICS processor supplied valuable statistical information such as relative spectral response values, standard deviations, and multispectral response graphs and histograms. The same sets of classes of training samples served to train the computer to classify each of the data points from the investigated area. A pattern recognition technique was used where unknown data were compared to the known sample response. Appropriate computer symbols were assigned to each group of samples so that on a computer classification map it was easy to distinguish one soil group from another.

b. Results

Obtained results indicate that ERTS data are an effective tool to map and distinguish different soil associations in a large geographic area such as entire counties. Figure shows a general soil map of Crosby County, Texas with seven soil associations. Figure 5 represents classification results obtained by computer analysis with December 1972 data.

Pullman soils (1), soils of the High Plains in the northern and northeastern part of the county, have the lowest spectral response compared to other soils. Their surface is dark brown granular, silty clay loam, well-drained, irrigated. It is mostly used to raise cotton, grain sorghum and wheat. Pullman silty clay loam, 1-3% slope, occurs mostly along the outer rim of playas scattered throughout the northern and northeastern part of the county.

The west central part of the county is covered by Olton soils. They are reddish to brown in color on their surface and contain less clay than Pullman soils. The major crops are cotton, grain sorghum and wheat. Reflectance from these crops is higher and the index is lower than these values for Pullman soils (Table 1). Index indicates a ratio between the visible and the infrared reflectance. Olton soils are light in color and contain less organic matter than Pullman soils.

Soil associations Amarillo (3) and Amarillo-Brownfield (4) of the High Plains are sandy soils. Amarillo soils are found mostly in the southwest part of the county. Their surface is granular, brown to reddish brown, fine sandy loam. They have less clay, and they are more friable than Olton soils. Grasses, cotton and grain sorghum are the principal cultivated crops on these soils. If left unprotected, Amarillo soils are susceptible to wind and water erosion. Brownfield soils occur in the west central and southeastern parts of the county. They are fine sandy soils, having a thicker, more sandy surface than Amarillo soils. Brownfield soils are highly susceptible to wind erosion and are poorly suited to cultivation. Most of the area remains in rangeland.

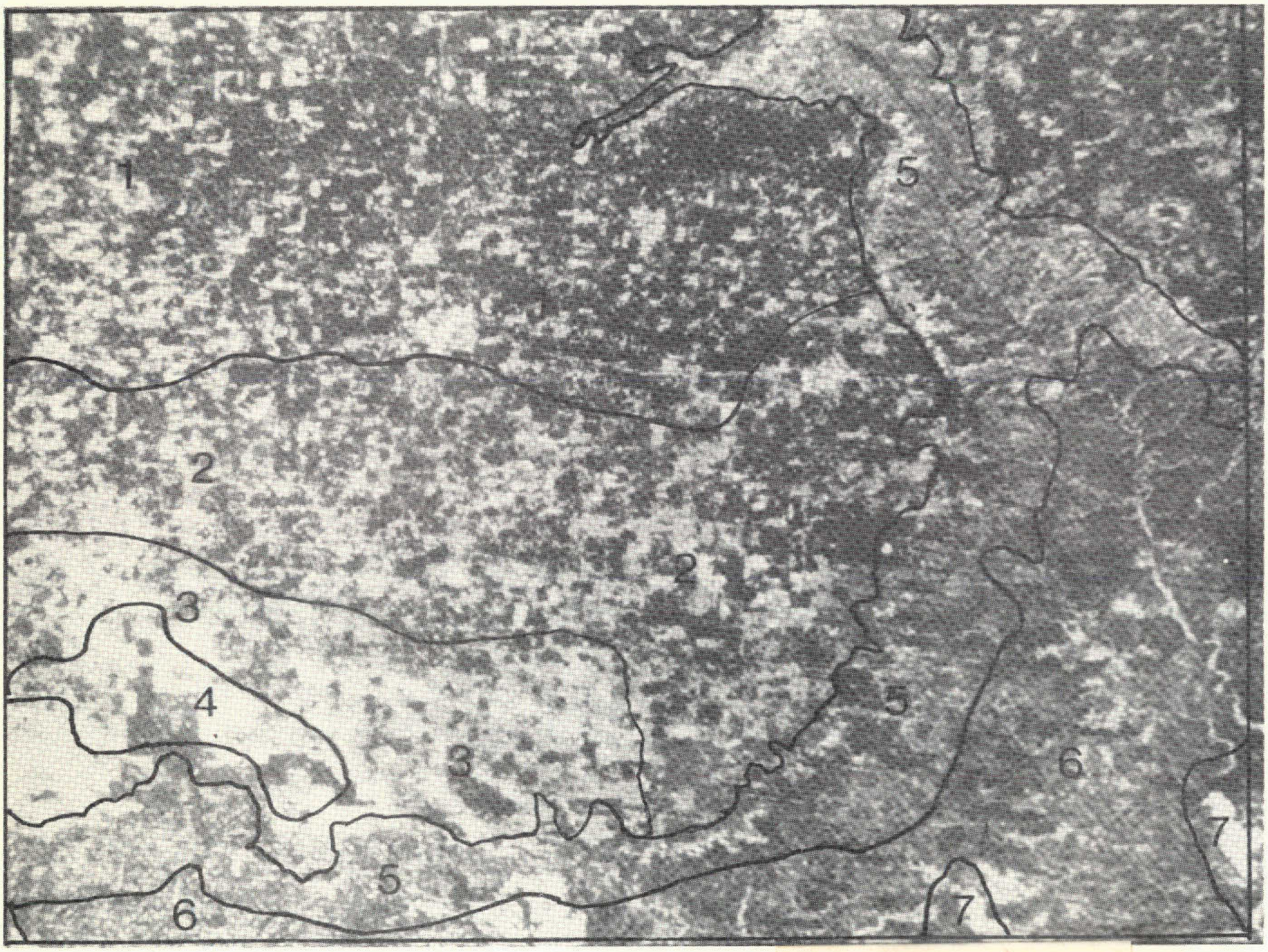


Figure 3. Classification of Crosby County Soils from ERTS Data Collected 9 October 1972.

1. Pullman Association
2. Olton Association
3. Amarillo Association
4. Amarillo-Brownfield Association
5. Berthoud-Mansker-Potter Association
6. Miles-Mansker Association
7. Brownfield-Miles Association

Table 1 . Relative Spectral Response for Crosby County, Texas Soil Associations, Using 9 October 1972 ERTS Data.

	Relative Spectral Responses*			
Soil Associations	Sum	% Visible	% IR	Index**
Pullman: deep hard land	116.04	45.82	54.18	0.846
Olton: mixed land	118.55	49.00	50.99	0.961
Amarillo: moderately sandy land	128.78	48.43	51.56	0.930
Amarillo-Brownfield: sandy land	155.63	47.65	52.34	0.910
Berthoud-Mansker-Potter: shallow land	119.72	51.67	48.32	1.068
Miles-Mansker: moderately sandy land	104.91	50.68	49.31	1.028
Brownfiled-Miles: sandy land	157.01	50.04	49.95	1.001

Table 2 . Relative Spectral Response for Crosby County, Texas Soil Associations, Using 14 November 1972 ERTS Data.

	Relative Spectral Responses			
Soil Associations	Sum	% Visible	% IR	Index
Pullman: deep hard land	87.85	56.33	43.66	1.290
Olton: mixed land	93.51	55.62	44.35	1.254
Amarillo: moderately sandy land	103.28	55.40	44.59	1.242
Amarillo-Brownfield: sandy land	124.44	53.76	46.23	1.163
Berthoud-Mansker-Potter: shallow land	93.53	55.20	44.79	1.232
Miles-Mansker: moderately sandy land	83.14	54.52	45.47	1.199
Brownfield-Miles: sandy land	127.84	54.23	45.77	1.185

*Average spectral value for all data points classified under each association.
**Index = % Visible divided by % IR.

The Amarillo-Brownfield soils complex has a higher spectral response than other soil groups of the High Plains. This is due to their properties: the soil surface is light in color, the subsoil is yellowish-red sandy clay loam on wind-laid deposits. They have a low moisture holding capacity, and at the time when the data were collected, appeared to be the driest soils in the area.

The soils of the Rolling Plains belong to two groups: shallow soils or badlands represented by the Berthoud-Mansker-Potter soil association (5), and sandy soils by the Miles-Mansker (6) and Brownfield-Miles association (7).

Badland consists of shale and clay derived from red beds, usually surrounded by steep sandstone escarpments. Between the escarpments are less sloping areas in gullies and ridges. The highly erodible clay from the red beds was washed away and entrenched valleys and gullies remain. The Berthoud-Mansker-Potter soil complex are badland soils. Berthoud soils, dark calcareous soil, are found on the foot slopes below the steep Caprock Escarpment. The Mansker soils are also calcareous soils but lighter in color than Berthoud soils. The Potter soils are very shallow, well drained soils along the smooth plains below the steep escarpment. The ratio (index) of the visible (0.50-0.70μm) and reflective infrared (0.70-1.10μm) portion of the spectrum of this association is like the Olton association or irrigated land.

At this time of the year (2 December 1972) the spectral responses of moderately sandy land (Miles-Mansker association) and sandy land (Brownfield-Miles association) are similar to those of the High Plains.

The classification results on Figures 3, 4, 5, and 6, the statistical information provided in Tables 1, 2, 3, and 4, show that the best spectral differentiation between soil associations is obtained in December and November when the soils are bare. With the data taken in October, the computer classification shows soil patterns in addition to soil cover. The relative mean values of the reflected energy in the reflective portion of the spectrum are higher for the soils of the High Plains than for the Rolling Plains soils. Therefore, it means that the area of the High Plains is still covered by green vegetation but the vegetative cover of the Rolling Plains is dry or sparse.

Analysis of the data taken on 18 June 1973 (Table 4 and Figure 4) shows that the ground is mostly exposed even though planted. Ratios between visible and reflective IR spectra will depend on how much ground is covered by vegetation.

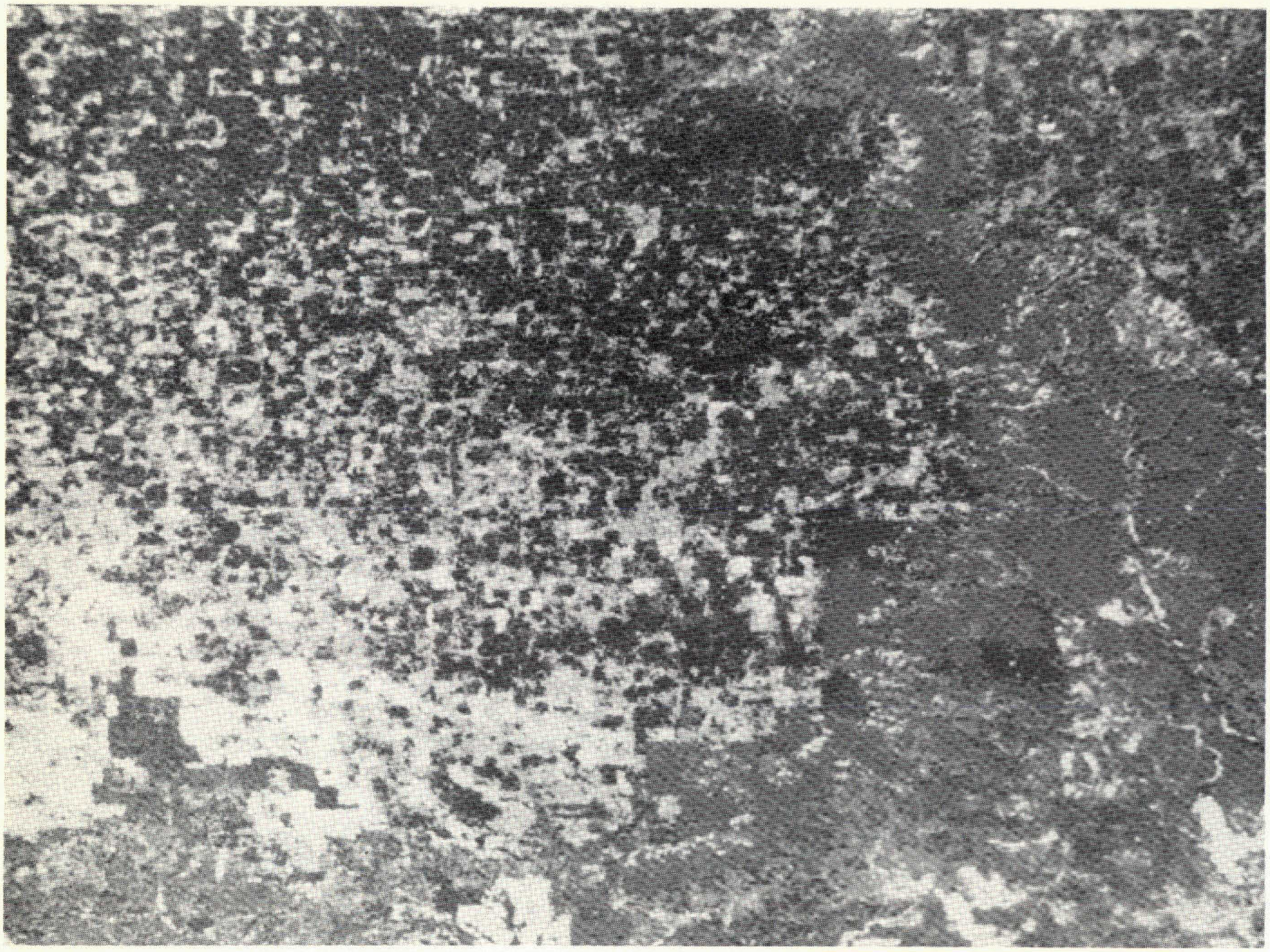


Figure 4. Classification of Crosby County Soils from ERTS Data Collected 14 November 1972.

1. Pullman Association
2. Olton Association
3. Amarillo Association
4. Amarillo-Brownfield Association
5. Berthoud-Mansker-Potter Association
6. Miles-Mansker Association
7. Brownfield-Miles Association

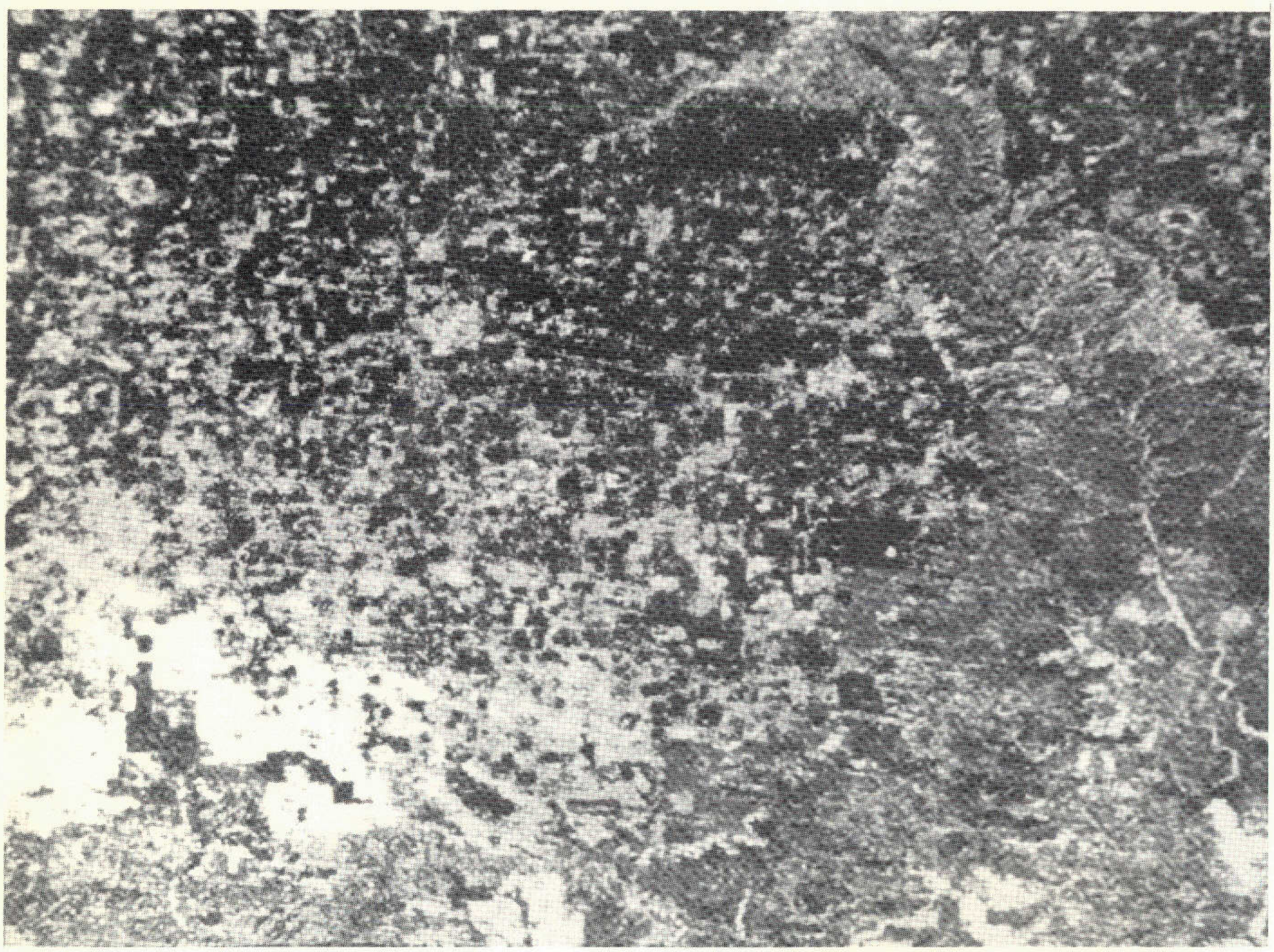


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Figure 5. Classification of Crosby County soils from ERTS data collected 2 December 1972.

1. Pullman Association
2. Olton Association
3. Amarillo Association
4. Amarillo-Brownfield Association
5. Berthoud-Mansker-Potter Association
6. Miles-Mansker Association
7. Brownfield-Miles Association

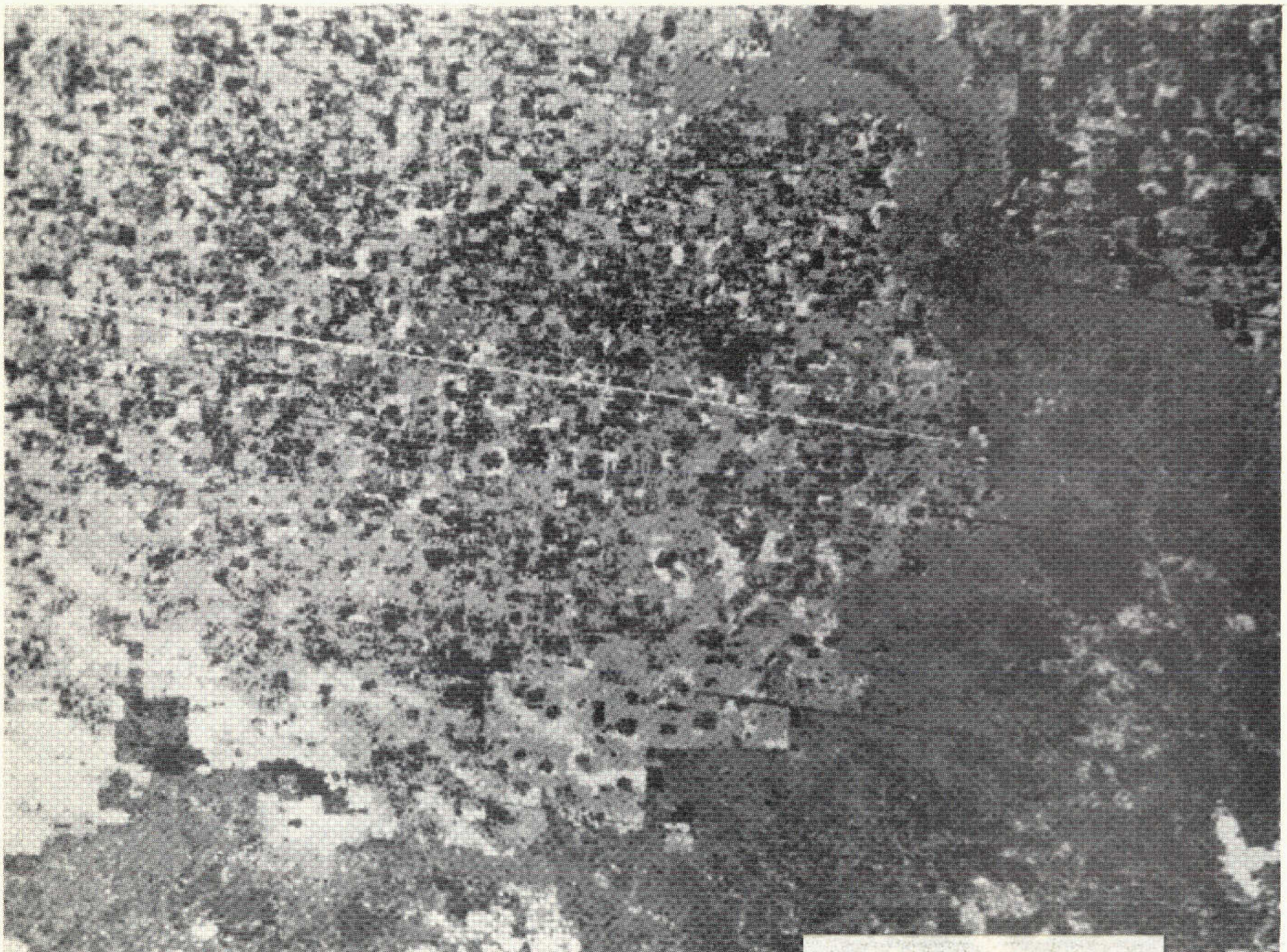

Figure 6. Classification of Crosby County Soils from ERTS Data Collected 18 June 1973.

1. Pullman Association
2. Olton Association
3. Amarillo Association
4. Amarillo-Brownfield Association
5. Berthoud-Mansker-Potter Association
6. Miles-Mansker Association
7. Brownfield-Miles Association

Table 3. Relative Spectral Response for Crosby County, Texas Soil Associations, Using 2 December 1972 ERTS Data.

Soil Associations	Relative Spectral Responses* Sum	% Visible	% IR	Index**
Pullman: deep hard land	70.17	57.05	42.95	1.328
Olton: mixed land	76.22	55.90	44.10	1.267
Amarillo: moderately sandy land	83.48	55.72	44.27	1.259
Amarillo-Brownfield: sandy land	105.51	53.93	44.27	1.171
Berthoud-Mansker-Potter: shallow land	81.87	55.90	44.09	1.268
Miles-Mansker: moderately sandy land	75.56	55.59	44.40	1.252
Brownfield-Miles: sandy land	113.23	54.31	45.68	1.189

Table 4. Relative Spectral Response for Crosby County, Texas Soil Associations, Using 18 June 1973 ERTS Data.

Soil Associations	Relative Spectral Responses Sum	% Visible	% IR	Index
Pullman: deep hard land	146.22	53.39	46.60	1.146
Oltnn: mixed land	153.62	53.29	46.71	1.141
Amarillo: moderately sandy land	155.10	53.30	46.70	1.142
Amarillo-Brownfield: sandy land	192.43	51.89	48.20	1.074
Bertoud-Mansker-Potter: shallow land	168.97	51.81	48.18	1.075
Miles-Mansker: moderately sandy land	140.95	51.21	48.78	1.050
Brownfield-Miles: sandy land	195.02	53.03	44.96	1.129

*Average spectral value for all data points classified under each association.

**Index = % Visible divided by %IR.

The rangeland during this time of year reflects much higher in the reflective infrared spectrum than Pullman, Olton or Amarillo soil associations. Their ratios are low except for the eroded parts or sand dunes.

c. Conclusions

Research on identifying and characterizing soils from ERTS data yielded the result that ERTS data may be used successfully in soil mapping in the same manner as aircraft data. Analyzing data in four different ERTS cycles, temporal changes on soil surfaces were identified and mapped. The spectral radiation characteristics of soils were seen to vary with seasons. The best spectral observation was obtained with the soil free of green vegetative cover. However, this does not exclude the usefulness of spring and summer data in soil studies.

2. LAMB COUNTY, TEXAS SOIL STUDY

Lamb County is in the southwestern part of the Texas Panhandle. Most of the area is a nearly level to gently undulating plain. The main industry is agriculture of which more than half is irrigated. Much of the acreage in the southwestern part of the county is dry-farmed. Cotton, corn and grain sorghum are the main crops.

The soil in Lamb County is divided into eight areas or major soil series, similar to soil associations. The most extensive soil in the county are soils of the Amarillo series. Amarillo fine sandy loam has a reddish brown surface. It is a productive soil; and the hazards of wind and water erosion are moderate. Amarillo loam is associated with Olton soils.

Tivoli-Brownfield sandy soils move through the county from west to east. They are light in color. Most of the soil series is in rangeland. The high hazard of wind erosion makes these soils poorly suited to cultivation.

A type of soil which occurs in all parts of the county belong to Portales series. They are calcareous shallow soils with grayish brown surface.

Along the draws and escarpments are the Berthoud series developed from material that eroded from higher lying soils. Associated soils are Mansker soils which are darker soils and less deep. Both soils are subject to wind erosion, and both are shallow.

Low rainfall, high winds and the hazard of erosion are major factors that determine the management practices employed in the county. Two remarkable practices used in the county are terracing and contour farming. These practices hold water where it falls and reduce water erosion.

About 20 percent of the land in Lamb County is used for range. The largest range area is a belt of sand hills running east and west through the central part of the county, with smaller areas around Saline Lakes in the south-central part, large draws in the central part of the county, and isolated playa lakes and sand dunes throughout the county. The rangelands are mostly covered by a wide variety of grasses. Mesquite, yucca, and brown snakeweed have invaded range sites. The rangelands occur as well defined areas.

Lamb County has a semiarid, warm continental climate. Hail frequently damages crops during the thunderstorms of early summer.

a. Objective

The objective of this analysis was to map soils of Lamb County, Texas utilizing ERTS data taken on 6 July 1973 (Scene ID 1348-16533).

b. Procedure

The capability of the ERTS program to obtain data over the same geographic area every 18 days provides the opportunity to analyze seasonal changes of certain geographic regions. Registration of multitemporal and geometrically corrected data, techniques recently developed at LARS, makes a big contribution in the further improvement of soil pattern identification. With this new approach, the 6 July 1973 ERTS frame (Scene ID 1348-16533) was used for analysis. False color images of the investigated area were observed. The color composites were made from bands 0.5-0.6μm, 0.6-0.7μm, and 0.8-1.10μm. These images have provided correction information on soil associations in Lamb County, Texas. The soil association map (1:190,080 scale) of the county was used to overlay the ERTS color imagery of approximately the same scale.

A digital image display system was used to display the data in a raster scanning mode on a standard television screen. With the light pen a set of samples of each soil series was selected from the data. These sets served as training sets for computer-implemented analysis. For every training set and for every sample within the set, the LARSYS STATISTICS processor supplied valuable statistical information such as relative spectral response values, standard deviations, and multispectral response graphs and histograms. The same sets of classes of training samples served to train the computer to classify each of the data points from the investigated area. A pattern recognition technique was used where unknown data were compared to the known sample response. Appropriate computer symbols were assigned to each group of samples so that on a computer classification map it was easy to distinguish one soil group from another.

c. Results

Soils are usually interpreted by the size and shape of the various components of the landscape and by soil-plant relationship. To a large extent, interpretation of the soils of Lamb County observed in the middle of the summer is reduced to interpretation of the herbaceous and shrubby vegetation.

Table 5 shows that the entire observed area was under vegetation cover. By using the ratio between the relative

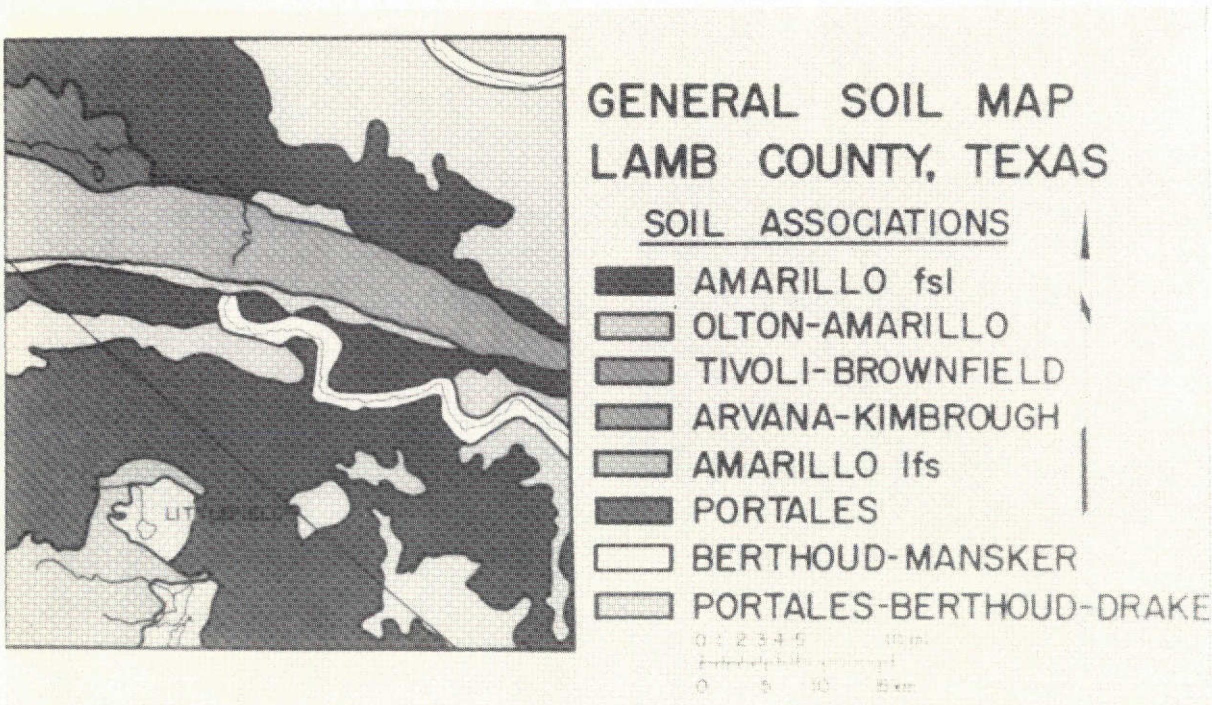

Figure 7. Soil series map of Lamb County, Texas.

Table 5. Relative Spectral Response for Lamb County, Texas Crops, Using 6 July 1973 ERTS-1 Data.

Crops	Relative Reflectance Values 0.50-1.10	% / 0.50-0.70	% / 0.70-1.10	Index
Alfalfa	159.89	44.79	55.20	0.812
Rye	176.54	55.09	44.90	1.227
Grain sorghum	158.19	44.64	55.35	0.807
Cotton	189.81	51.05	48.96	1.043
Corn	135.67	34.88	65.11	0.535
Pasture	147.06	52.90	47.09	1.123
Others	213.18	53.08	46.91	1.132

reflectance values of the reflective infrared region, one is able to see clearly the existing relationship between soils and vegetation.

Amarillo sandy loams, the best dryland soils with moderate erosion and granular structure, in irrigated and nonirrigated areas have a high magnitude of reflectance compared with other soils in the county. Olton-Amarillo complex, the best complex for irrigation farming, does not have a high magnitude of reflectance because they are under irrigation; however, their index is one of the lowest showing their high productivity. The Olton-Amarillo soils in this time of year are covered with dense vegetation.

The soils in range areas reflect higher in the visible than in the reflective infrared portion of the spectrum, therefore their index is higher than 1.00 even though under vegetation.

The classification results (Figure 8) show that Amarillo loams are very difficult to observe separately from Olton-Amarillo loams (two large soil series in the county) in July. Very good contrast is obtained between soils in rangeland and soils in the irrigated sections of the county, even if both areas were under vegetation.

d. Conclusion

Using spectral data in soil mapping is very difficult to do with data collected in the summer or early fall. The results of this work demonstrate that soils under vegetation do not reflect directly, but can be interpreted by using the covering vegetation.

Table 6. Relative Spectral Response for Lamb County, Texas Soil Series, Using 6 July 1973 ERTS-1 Data.

Area	Dominant Soil Series	Relative Reflectance 0.50-1.10μm Magnitude of Reflectance	% 0.50-0.70μm	% 0.70-1.10μm	Index
1	Amarillo sandy loams	162.71	44.88	55.11	0.814
2	Olton-Amarillo loams	150.77	43.21	56.78	0.761
3	Tivoli-Brownfield fine sands	149.11	51.48	48.51	1.061
5	Amarillo loamy sand	207.52	69.85	50.15	0.994
6	Portales loams	155.13	50.93	49.06	1.038
7	Berthoud-Mansker sandy loams	174.74	52.04	47.95	1.185

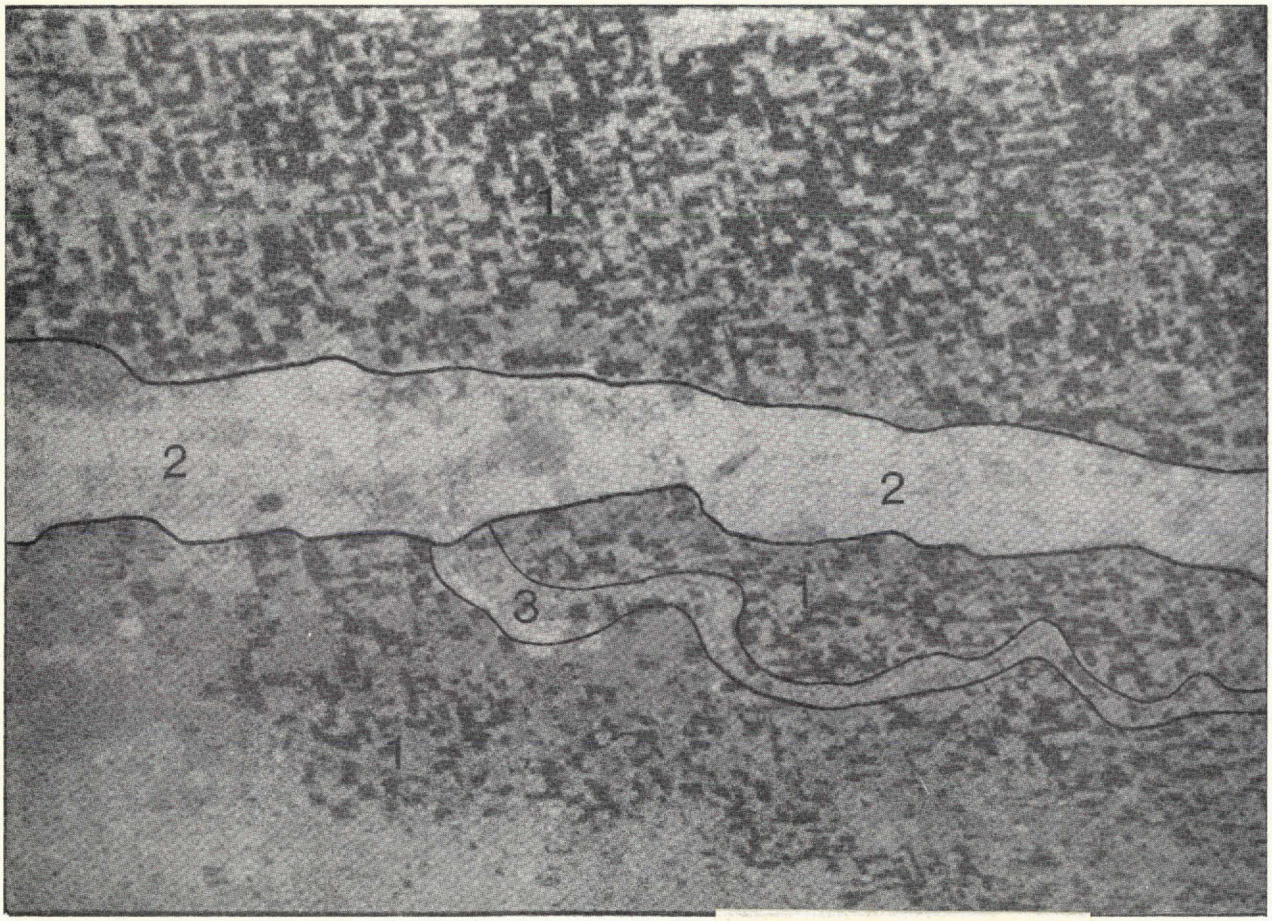

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Figure 8. Classification of Lamb County, Texas Using Data Collected 6 July 1973.

1 - Undifferentiated soils (see Figure 7)
2 - Tivoli-Brownfield soils
3 - Berthoud-Mansker soils

3. LUBBOCK COUNTY, TEXAS

a. Land Use Study

The following manuscript was presented at the Fourth Annual Conference on Remote Sensing of Arid Lands, Resources and Environments, Tucson, Arizona, November 1973, under the title "Preparing Resource Inventories in the Southern Great Plains by Machine-Processing of ERTS-1 Multispectral Data" by James A. Henderson, Jr., M. F. Baumgardner and Carl F. Walker.

Introduction

Two areas, Lubbock County, Texas and Hobbs, New Mexico (Figure 9) located on the Llano Estacado were chosen for analysis. The areas are similar in economy, (mostly agricultural) and climate (arid to semiarid). Data were collected by the Earth Resources Technology Satellite during June 1973. Two methods of analysis were used in this study: (1) unsupervised for the Hobbs, New Mexico area, and (2) supervised for the Lubbock County, Texas area.

For this analysis no ground information was available for the Hobbs area. In the Lubbock area, the analysts had high quality ground information in addition to some personal knowledge of the area. The availability of ground information contributed greatly to the success and interpretation of the classification of the Lubbock County data.

Procedures

Remote sensing data from the Earth Resources Technology Satellite (ERTS-1) were used in this investigation. The data are from the multispectral scanner and are in the form of computer compatible tapes.

The bands of the multispectral scanner are in the visible and near infrared region of the spectrum: channel 4--0.50-0.60 μm, channel 5--0.60-0.70 μm, channel 6--0.70-0.80 μm and channel 7--0.80-1.10 μm.

LARSYS Version III is a package of computer programs designed to analyze and display remotely sensed multispectral data using an IBM System 360 computer. Five major processing algorithms were used in this study: (1) CLUSTER, (2) STATISTICS, (3) CLASSIFYPOINTS, (4) PRINTRESULTS, and (5) PHOTO. The CLUSTER processor is an unsupervised classifier that groups data vectors into spectrally distinct classes. Mean vectors and covariance matrices are calculated by the STATISTICS processor which performs a maximum likelihood Gaussian classification on a point-by-point basis over the entire area. Results

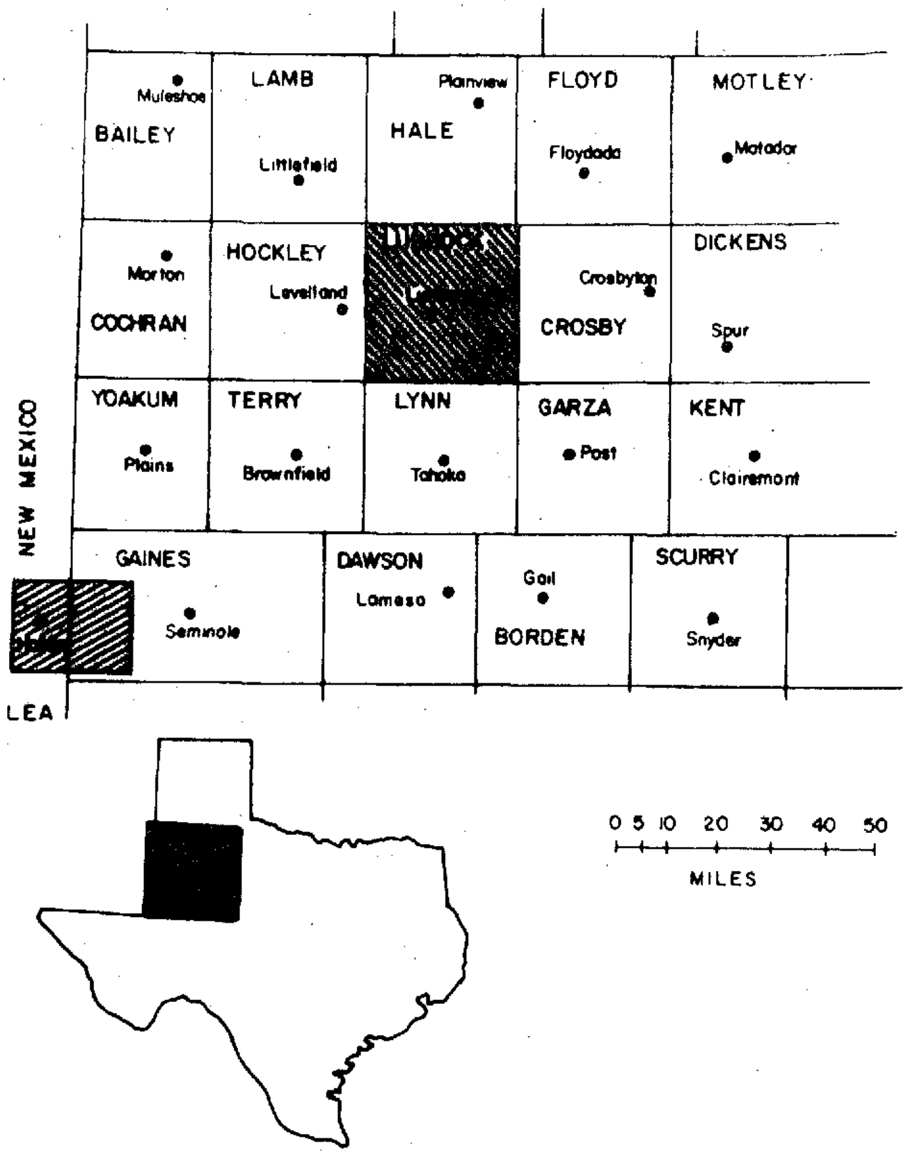

Figure 9. Index Map.

from the above analysis are displayed using: (1) the PRINT-RESULTS processor to make alphanumeric maps; and (2) the PHOTO processor to display the results on the digital display.

The Digital Image Display System receives an image from a System 360 computer, stores this data in a video buffer, and displays the image in a raster scanning mode on a standard television screen. An interactive capability to edit, annotate, or modify the image is provided through a light pen and a program function keyboard. An additional photographic copying capability is also provided.

Description of Study Area

The areas analyzed in this investigation are on the Southern High Plains of Western Texas and Eastern New Mexico. This area, known as the Llano Estacado, is a plateau bordered by escarpments on the east, west, and north and on the south by the Edwards Plateau. The plateau is essentially flat with a dip of approximately .1° to the southeast.

The only topographic features on the Llano Estacado are several broad shallow draws and a large number of shallow playas. The draws are very shallow and broad except near the escarpment where they become steep sided canyons. Numerous shallow playas are present on the Llano.

The study area is arid to semiarid and generally receives from 31 to 53 centimeters (15 to 21 inches) of precipitation per year. Wheat, cotton, and grain sorghum are the major crops and are grown under irrigated and dryland conditions.

Hobbs, New Mexico Analysis

Data collected by ERTS on 19 June 1973 (Scene ID 1331-16585) were analyzed by unsupervised methods without ground information or air photos. Initial inspection of the data was made using a color composite photo produced from the digital display using ERTS bands 4, 5 and 7. A classification of the Hobbs area was generated by selecting a representative area, i.e. an area containing all of the expected surface features, and using the nonsupervised clustering algorithm in the LARSYS system to define the spectral classes which were present in the data. After the classification was made the results were displayed on output from the line printer and also on the digital display (Figure 10). Photo interpretation techniques were then used to identify features in the Hobbs area using both the classification results and the color composite photos.

Detailed interpretation of both the color composite and the classification indicated that general land use categories

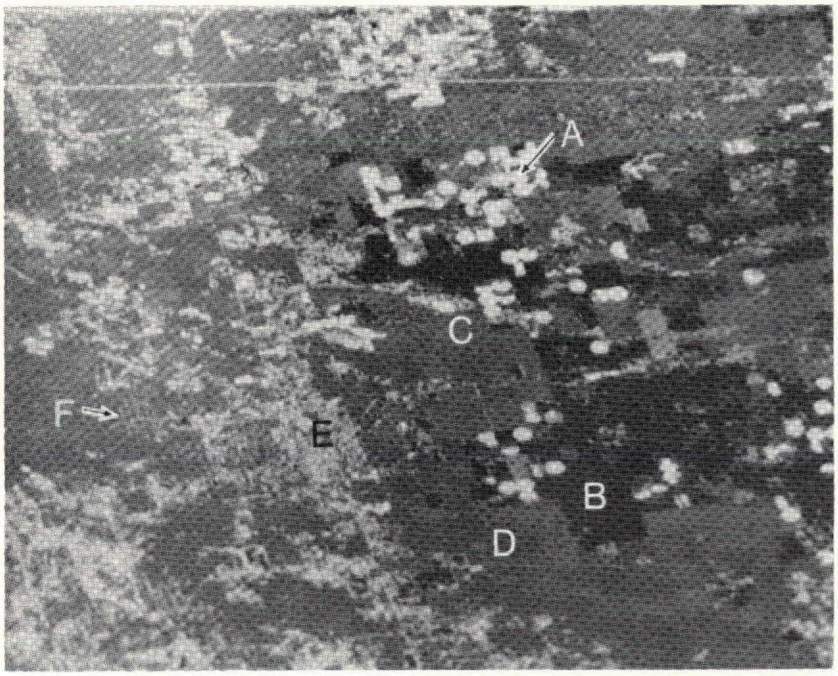

Figure 10. Unsupervised classification of an area around Hobbs, New Mexico.

A. Green Vegetation
B. Fallow
C. Green Pasture
D. Brown Pasture
E. Hobbs, New Mexico
F. Oil Field

could be easily distinguished (Figure 11). Agricultural areas, characterized by circular fields, were identified as either being in active cultivation or fallow. Pasture and natural rangeland were identified. It was possible to delineate areas of active growth of the plants both on the classification because the areas were classified as green vegetation, and on the color composite because of the red tones which are usually indicative of green vegetation. Man-made features such as airports, roads, oil fields, and urban areas were identified. The class containing man-made features included all highly reflective material such as natural outcrops of caliche, bare soil, and most hard surfaces. The naturally occurring highly reflective material could be separated from man-made features because of the differences in shape and location.

Lubbock County, Texas Analysis

ERTS data collected 18 June 1973 (Scene ID 1330-165331) were used in the preparation of a land use map for Lubbock County, Texas and the City of Lubbock. As in the Hobbs, New Mexico analysis, an initial inspection of the data was made using color composite photos taken from the digital display using ERTS bands 4, 5, and 7. Classifications of the Lubbock area were produced using supervised classification methods. Training areas, from which statistics were obtained to produce the classification, were selected on the basis of ground information obtained from the site. Ground information (Figure 12) consisted of high altitude (6,000 m.) color and color IR photography, low altitude (600 m.) oblique color slides, and personal knowledge of parts of the Lubbock area. Classification results were displayed on output from the line-printer and on the digital display unit.

Five classes of ground cover were identified in the classifications: (1) commercial, (2) residential, (3) green vegetation, (4) agricultural, and (5) water. None of the classes described above, with the possible exception of the agricultural and water classes, is characterized by a spectral response which is homogeneous, but rather by a combination of spectral responses from several types of materials. The commercial class is a combination of spectral responses from roofs, parking areas, and streets while the residential class is composed of roofs, streets, trees, and lawns. The green vegetation class consists of trees and grass. The agricultural class is composed of bare soil with very little vegetation on 18 June 1973. Using the above class definitions, misidentifications in the classifications can be more easily understood and explained.

Results from the analysis of Lubbock County were compared with available air photos and with the published topographic

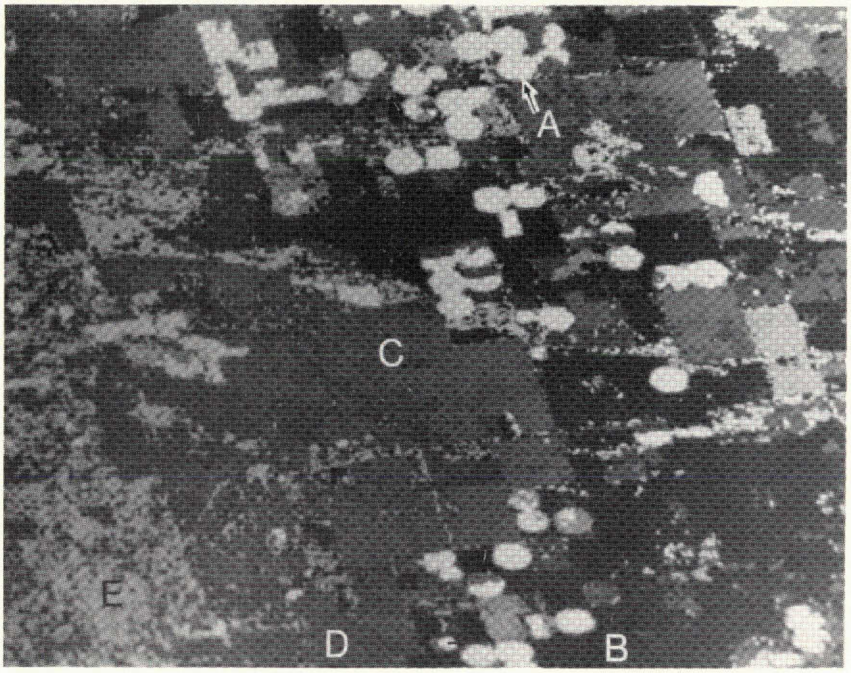

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Figure 11. Enlargement of a portion of Figure 10.

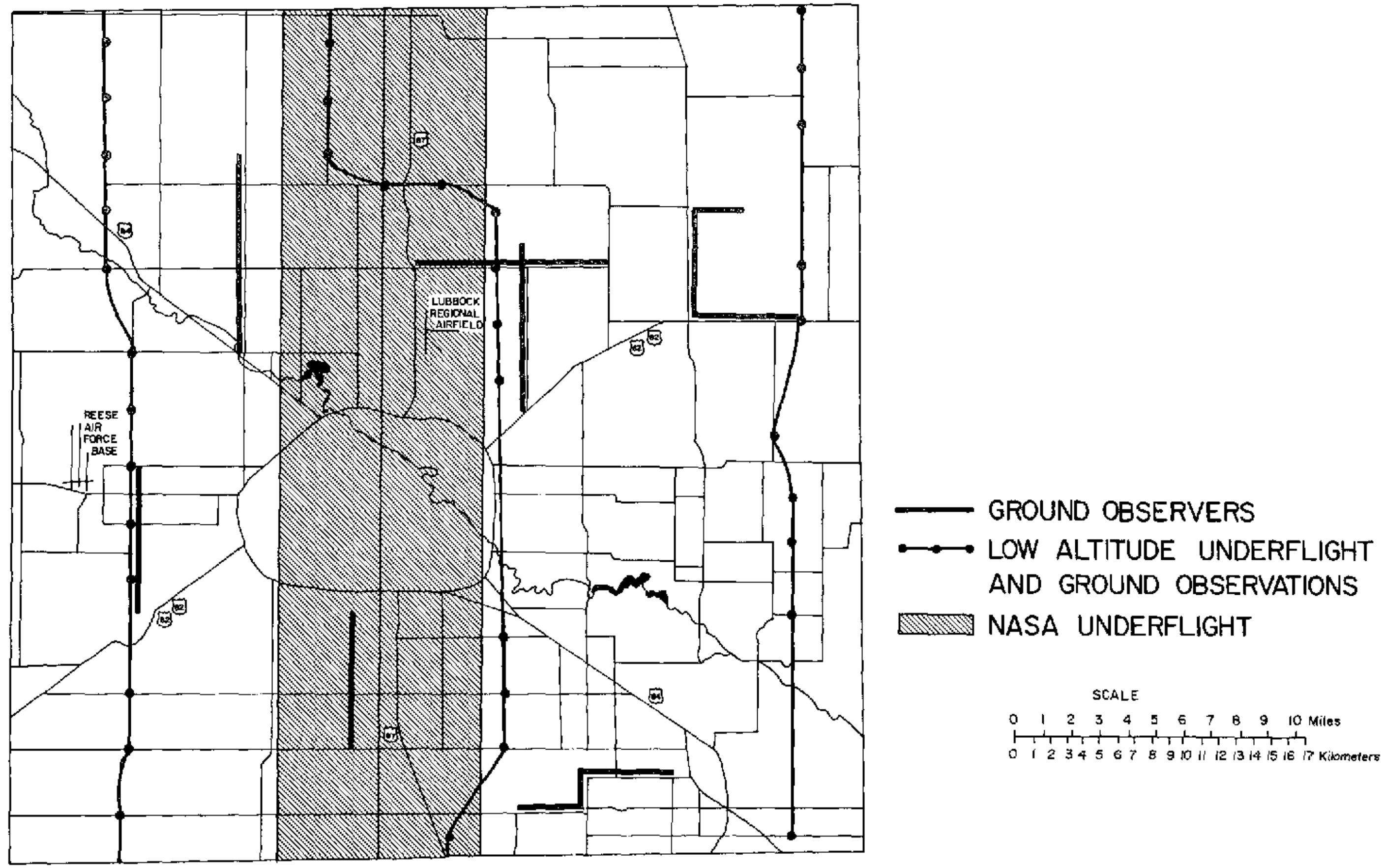

Figure 12. Location of ground information used in the analysis of Lubbock County, Texas.

maps. In the classification of the county area (Figure 13), small towns (A. New Deal, B. Idalou, and C. Slayton), airports (D. Reese AFB and E. Lubbock Regional Airport), and some water bodies (F. Buffalo Springs Lake) can be located and are correctly classified. There are, in the county classification, scattered points which were classified as residential or commercial, these are apparently farmsteads which contained mixtures of roofs, hard surfaces, and green vegetation.

When the classification results of only the city of Lubbock are compared with the aerial photography, many features can be identified. A comparison of black and white copies of color IR and color oblique photographs with the classification results from the city of Lubbock is shown in Figures 14 to 17. Areas of interest are identified by letters on the air photo which correspond to letters on the classification.

A comparison was also made between the classification results and the published USGS topographic maps which were made in 1957 and photo-revised in 1970 (Figure 18). This comparison was made to check the classification results and also to identify areas of urban growth. The most apparent growth has taken place in the western part of the city. As in the previous comparisons, areas identified by letters on the topographic map correspond to letters on the classification results.

Conclusion

From the work presented in this paper it can be concluded that proper analysis of multispectral scanner data can be used to produce a useful land use map. This conclusion should be considered in two parts: (1) the proper analysis procedures and (2) the usefulness of the resulting classification.

Both the nonsupervised and supervised classification procedures are useful for producing a land use map, with the selection of a procedure based on amount of ground information available and the amount of detail required in the finished product. The nonsupervised classification of the Hobbs, New Mexico area was made with no ground information, yet a reasonably accurate classification of urban, agricultural, and pasture area was made. Since no ground information was available, assignment of names of spectral classes is tentative and based on spatial inspection of the classification results and the original data.

The supervised classification of the Lubbock County, Texas area produced a very usable and accurate map. Because of the ground information that was available, the classes to be used in the classification could be accurately named and controlled. In

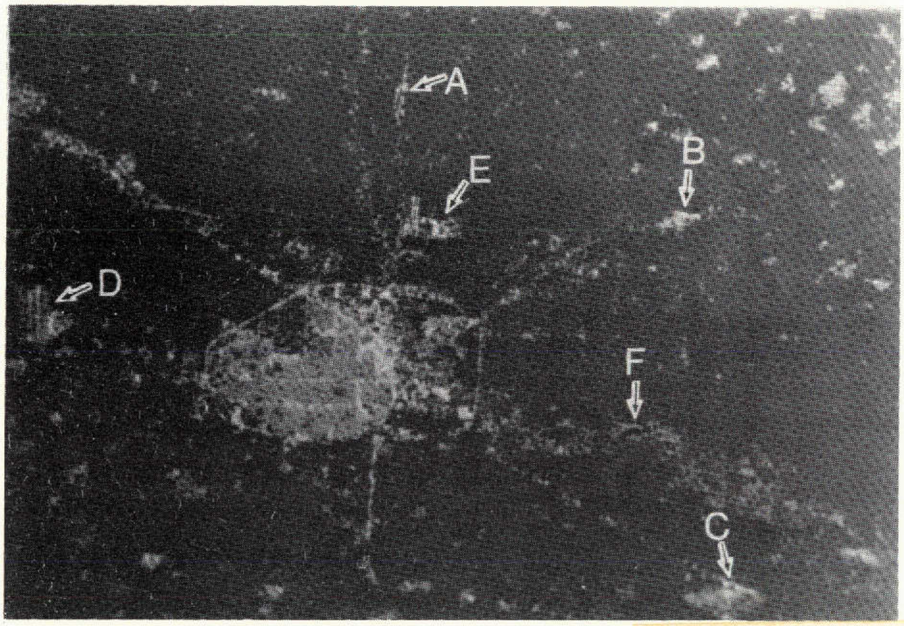

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Figure 13. Classification of Lubbock County, Texas.

Black - Water	A. New Deal
Dark Gray - Agriculture	B. Idalou
Light Gray - Residential	C. Slayton
White - Commercial	D. Reese AFB
	E. Lubbock Regional Airport
	F. Buffalo Springs Lake

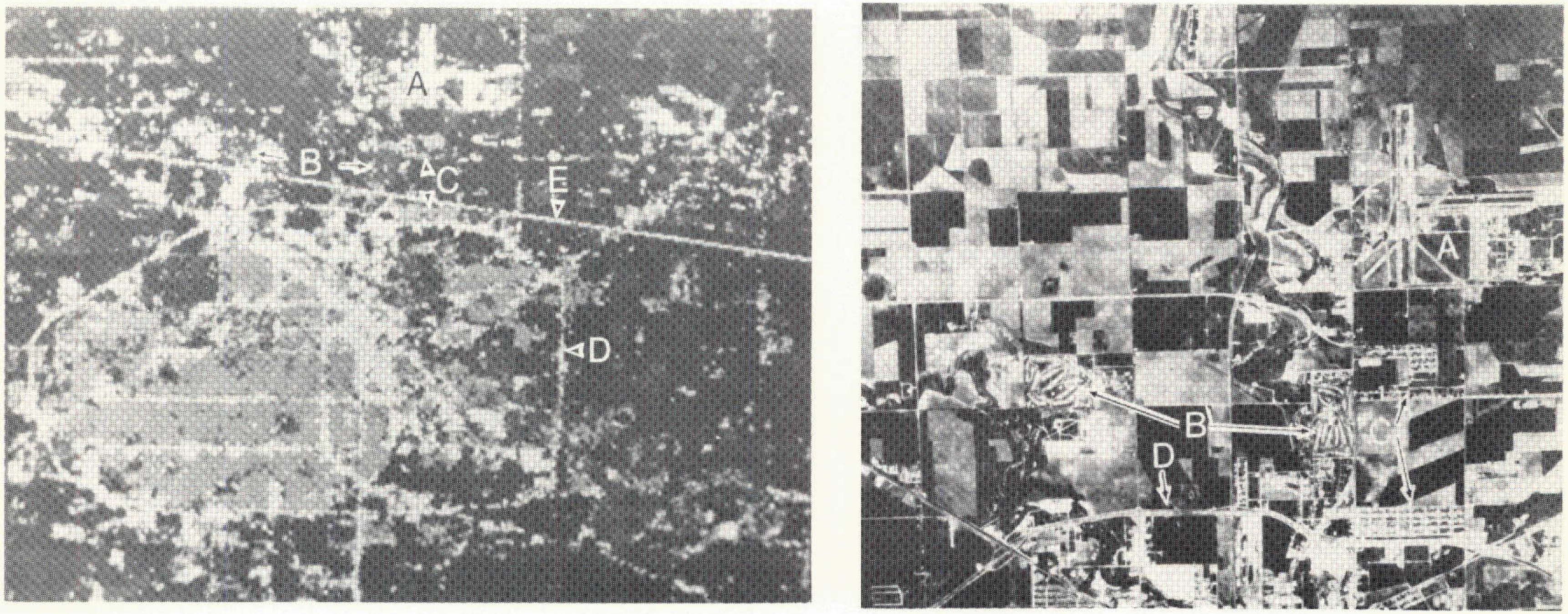

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Figure 14. Comparison of a classification of the City of Lubbock to a black and white copy of a color infrared photo.

A. Lubbock Regional Airport
B. Golf Courses
C. Residential Areas
D. Beltway
E. Bad Data Line

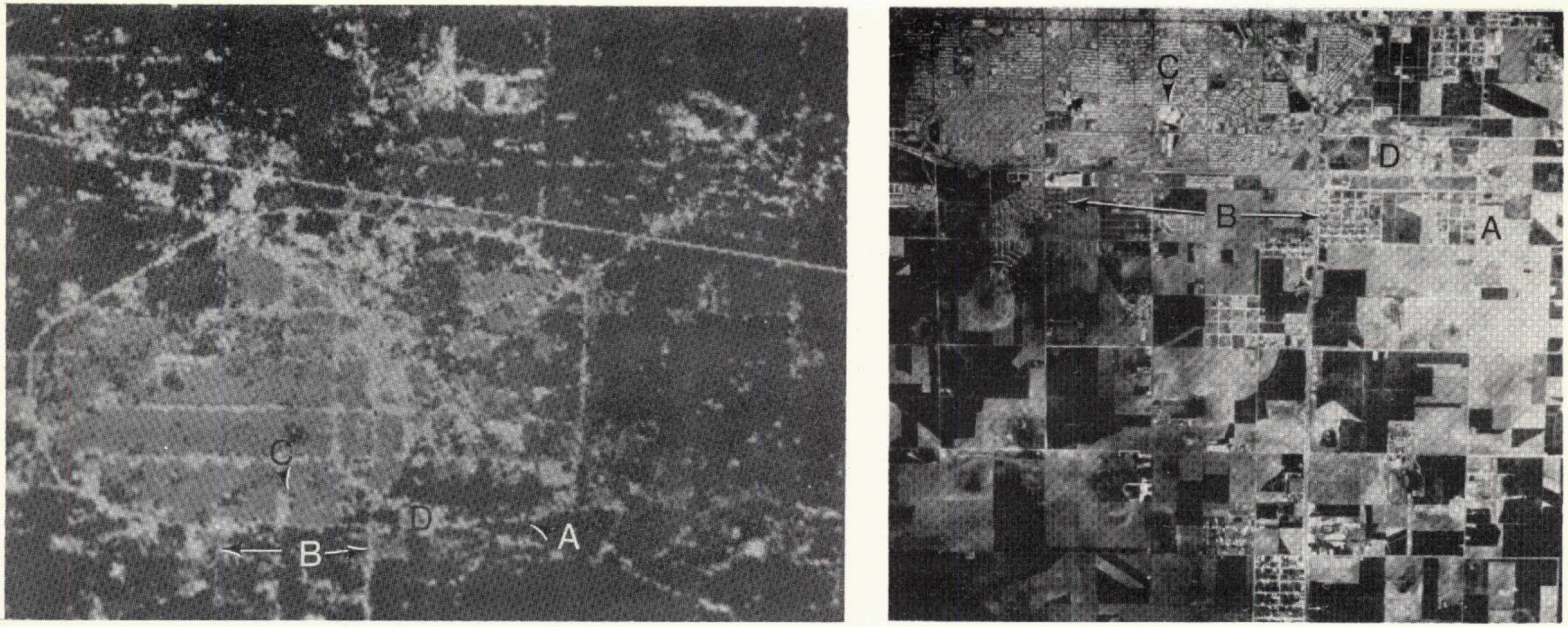

Figure 15. Comparison of classification of the City of Lubbock to a black and white copy of a color infrared photo.

A. Beltway	C. Drive-in Theaters
B. Residential Areas	D. Commercial Areas

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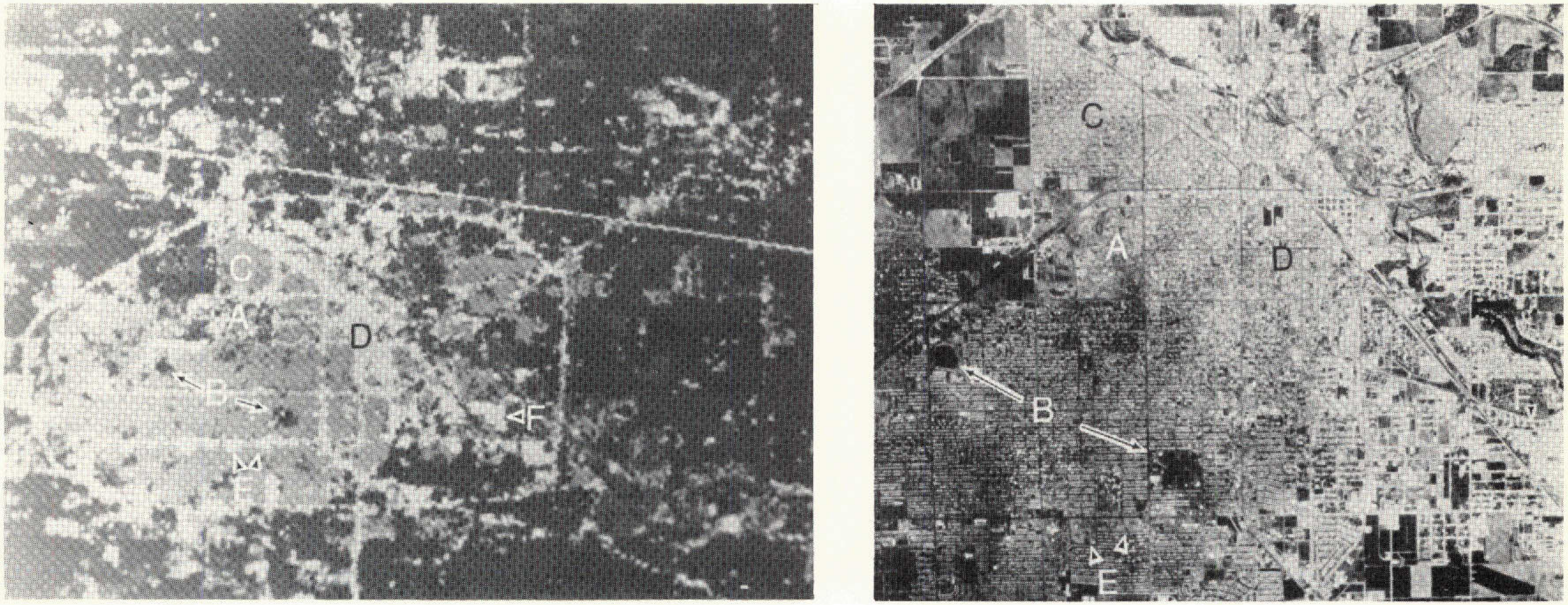

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Figure 16. Comparison of classification of the City of Lubbock to a black and white copy of an color infrared photo.

A. Texas Tech University Campus
B. City Parks
C. Residential Areas
D. Commercial Areas
E. Shopping Centers along a major east-west street
F. Warehouse Complex

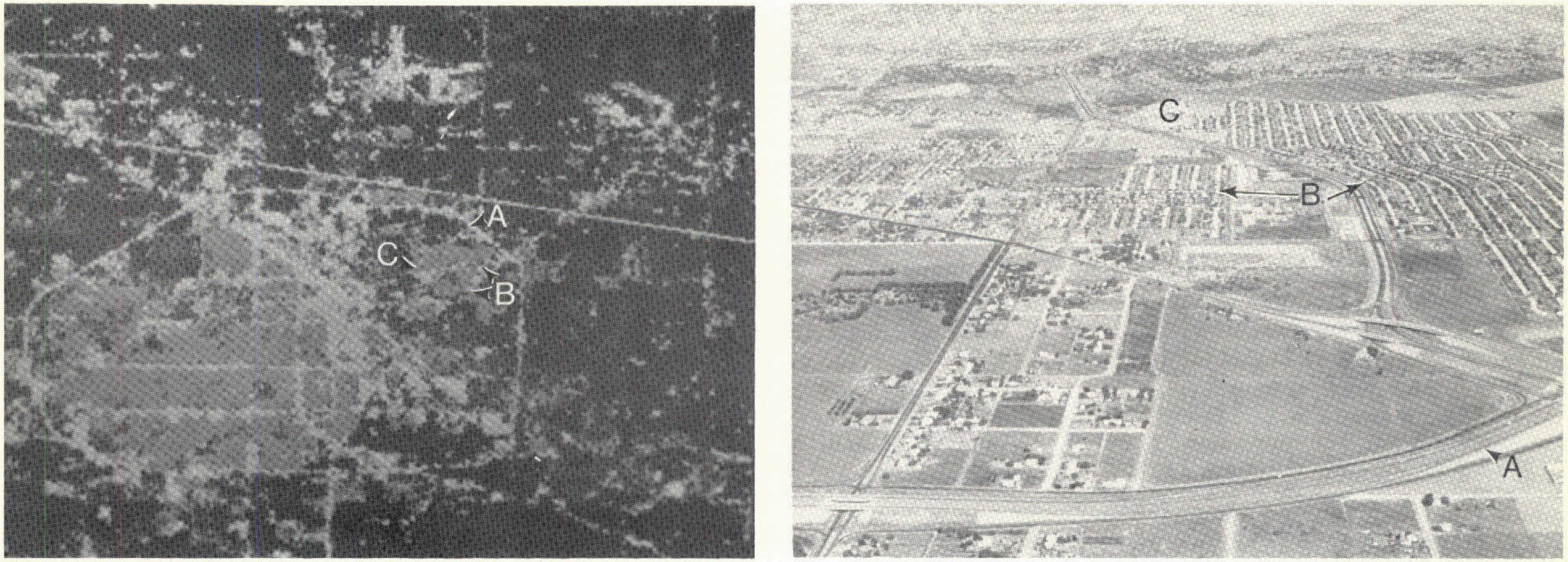

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Figure 17. Comparison of classification of the City of Lubbock to a black and white copy of a color photo.

A. Beltway
B. Residential Areas
C. Shopping Center

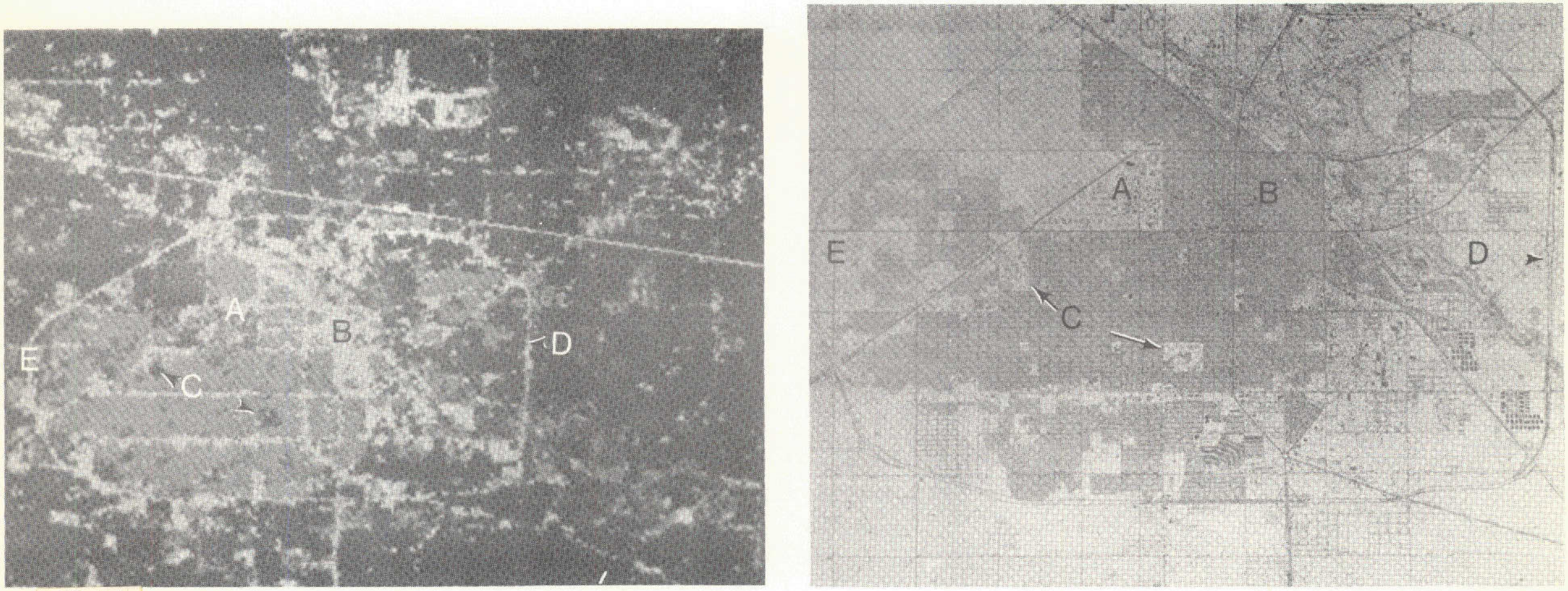

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Figure 18. Comparison of classification of the City of Lubbock to the USGS Lubbock East and West Quadrangle maps.

A. Texas Tech University Campus
B. Central Business District
C. City Parks
D. Beltway
E. Areas of Growth since the photo-revision of the maps

addition, classification results could be checked with the available photography and maps to determine its accuracy. The supervised classification, in this study, yielded the best results. For an operational system, a combination of supervised and nonsupervised classification methods would be used. It should be understood that supervised and nonsupervised methods of classification are two forms of machine-aided processsing and differ only in the degree of man-machine interaction.

The results from the classification, whether produced by supervised or nonsupervised methods, have the potential of replacing, or at least supplementing to a large extent, air photos as a data source in the production of land use maps. Machine processing of remote sensing data has several major advantages in producing land use maps, such as: (1) ability to map large areas, (2) speed of processing, and (3) accuracy. Land use maps of large areas can be produced quickly, accurately, and relatively inexpensively using machine processing of remotely sensed data.

b. Crop Identification Study

The purpose of this analysis was to produce a map of the crops of Lubbock County, Texas using ground information collected by volunteer ground observers. Cover types to be mapped included: Agriculture - cotton, grain sorghum, wheat, pasture; Urban - residential, commercial, transportation; and Water. Eight channels of data (four from 18 June and four from 24 July) were used in this analysis. The data were geometrically corrected and overlayed ERTS MSS data collected (Scene ID 1330-16531) and (Scene ID 1366-16521) 18 June and 24 July 1973.

Observations made by ground observers were used to locate areas of known cover type (Figure 12). A subset of these areas were used to train the computer as to the spectral characteristics of each cover type. These statistics were then used in the SEPARABILITY function to select the best four channels for this analysis. The best four channels according to the SEPARABILITY function were: 4 (0.50-0.60μm) and 5 (0.60-0.70μm) from 18 June and 4 (0.50-0.60μm) and 7 (0.80-1.10μm) from 24 July. These channels were then used to classify Lubbock County.

Two classifications were made, one using four channels from one date (24 July) and the other using four channels from two dates (procedure described above). The classification accuracy was tested using the areas of known cover type which were not used as training areas. The classification which provided the best results was the one which used four channels from two dates.

It was not possible, using the two ERTS passes that were available for this analysis, to separate spectrally cotton from grain sorghum (Figure 19). Because of this, cotton and grain sorghum were combined into one class - rowcrops. The 24 July data contained scattered cumulus clouds which was included as a class in the classification. The average performance by class for the classification using four channels from two dates was 89.3% and for the classification using four channels from the 24 July data was 86.1%.

Acreage estimates were made from the percentage of points in each class. The total area in the county was multiplied by these percentages to obtain an estimate of the area in each cover type. Tables 7 and 8 show the area estimates that were made from the classification of four channels from the two dates. The estimates for row crops and close grown crops (wheat) in Table 8 are higher than the figures that were received from the county extension office in Lubbock County.

The estimates we received were 152,634 hectares (377,158 acres) for row crops (cotton, grain sorghum, and soybeans) while the estimate obtained from ERTS (Table 8) is 167,224 hectares (413,210 acres) for cotton, grain sorghum, soybeans, and other minor row crops. No other figures were available with which to check the other categories in this classification, but the figures in Tables 7 and 8 appear to be what one would expect.

The two ERTS scenes used in this analysis (18 June and 24 July 1973) do not appear to be the best dates to use to separate cotton and grain sorghum. Possibly data collected later in the growing season, after the cotton bolls have opened but before the first frost would facilitate the easy separation of cotton and grain sorghum. Data from this part of the 1973 growing season were not available because of excessive cloud cover. Although cotton and grain sorghum have not been separated, it has been shown that temporally overlayed ERTS data can be useful in increasing classification accuracy.

LUBROCK
HENDERSON

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

FEB 26,1974
2 05 47 AM
LARSYS VERSION 3

COINCIDENT SPECTRAL PLOT (MEAN PLUS AND MINUS ONE STD. DEV.) FOR CLASS(ES)

LEGEND
A = CLASS 1 COTTON
B = CLASS 2 GR SOR

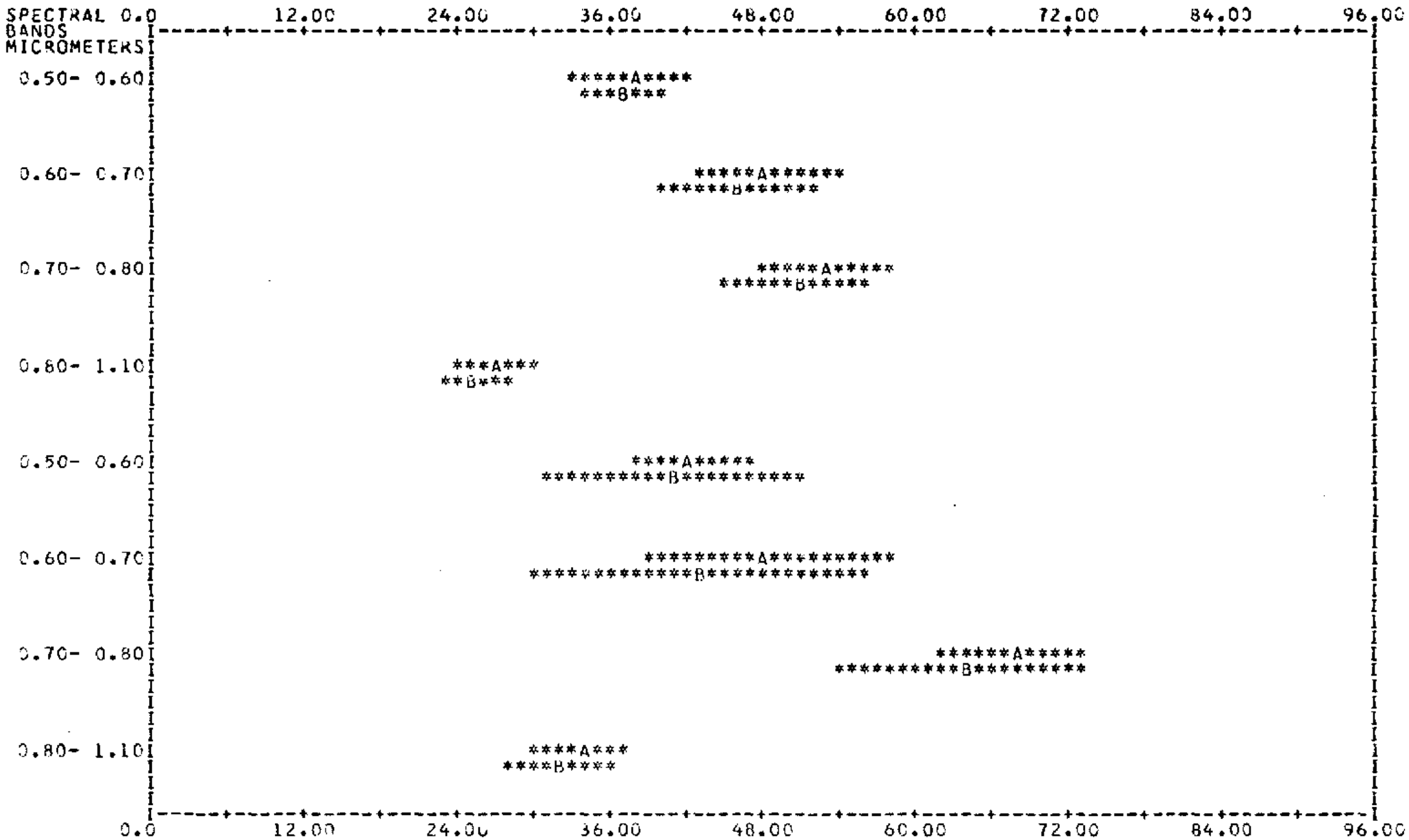

Figure 19. Coincident spectral plots of cotton and grain sorghum test fields for data obtained 18 June 1973 and 24 July 1973.

Table 7 . Area Estimates Made from Classification of ERTS MSS Data.

Cover Type	Points	%	Area Hectares	(Acreage)
Agriculture	386,867	92.69	215,938	(533,583)
Urban	33,125	7.21	16,757	(41,406)
Water	527	.11	266	(658)
Total	460,609	100.01	232,961	(576,000)

Table 8 . Area Estimates Made from Classification of ERTS MSS Data.

Cover Type	Points	%	Area Hectares	(Acreage)
Row crop	330,568	71.77	167,224	(413,210)
Wheat	52,707	11.44	26,662	(65,883)
Pasture	43,592	9.46	22,052	(54,490)
Urban	33,125	7.21	16,757	(41,406)
Water	527	.11	266	(658)
Total	460,609	99.99	232,961	(576,000)

4. LYNN COUNTY, TEXAS

a. Rangeland Study

A large portion of Lynn County, Texas (approximately 37,000 hectares) is rangeland. Using computer-aided data processing on ERTS MSS data a classification was made which attempted to show the degree of mesquite invasion in the rangeland. The ERTS data were from the 18 June 1973 pass (scene number 1330-165331).

By comparing the classification with available ground truth, color and color-IR photos taken 10 September 1972 and 20 March 1973 by NASA, and oblique low altitude air photos taken 5 July 1973, the accuracy of the classification was assessed. Three classes of pasture were identified: (1) clear pasture, mostly grasses; (2) mixture of grasses and mesquite; and (3) areas of thick mesquite. In addition, one class, called "other", included lakes and agricultural areas.

Differences in rangeland composition can be mapped from spectral data using computer-aided processing techniques. The T Bar Ranch which surrounds the Double Lakes west of Tahoka, Texas was chosen as a test area for the classification of rangeland. The classification of the T Bar Ranch area (Figure 20) shows the three classes of rangeland. The following tables summarizes the classification results of the T Bar Ranch and some of the surrounding agricultural land.

	Areas	Percentage
Agriculture and lakes	34494	45.9
Rangeland	40674	54.1
Total	75168	100.0

	Areas	Percentage
Clear pasture	25831	63.5
Mixture of grasses and mesquite	7285	17.9
Thick mesquite	7558	18.6
Total	40674	100.0

Two unexpected results were obtained in this investigation: (1) prairie dog towns in relatively clear pasture were classified as agriculture, and (2) dry lake beds were classified as bare soil (agriculture). Apparently prairie dog burrows in clear pasture compose enough of the surface area to be spectrally similar to cultivated agricultural land. Several large alkaline lakes, which were dry when the data were collected, were also spectrally similar to cultivated agricultural land. This was surprising because the lakes are highly reflective alkaline lake deposits while the soil is a brown or reddish brown sandy soil. In both of the above cases of misclassification, confusion can be minimized by using spatial data obtained from maps or air photos for making the final analysis.

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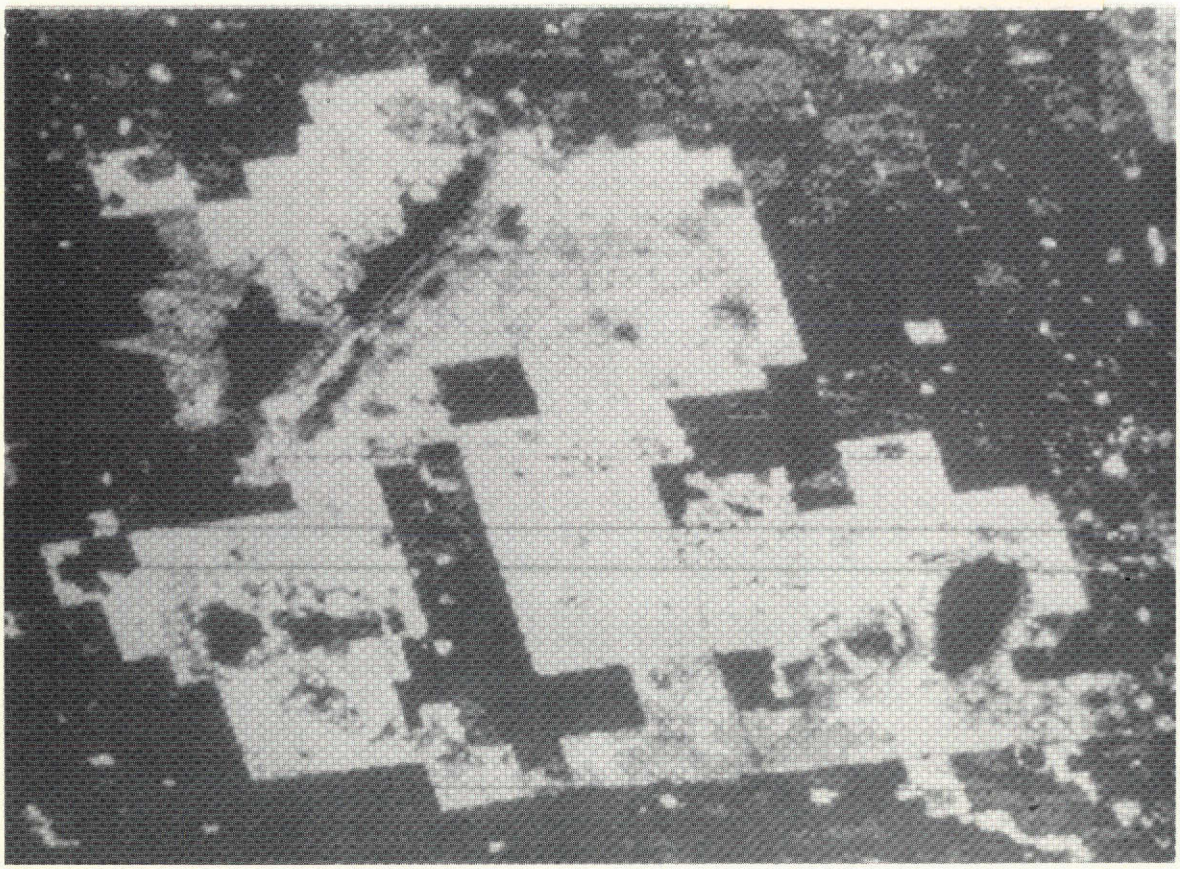

Figure 20. Rangeland classification of Double Lakes and T-Bar Ranch area in Lynn County, Texas.
Black - Agriculture and Lakes
White - Grasses
Light Gray - Mixture of Mesquite and Grasses
Dark Gray - Mesquite

b. Soils Study

Multispectral reflectance data were obtained over Lynn County, Texas on 2 December 1972 (Scene I.D. 1132-16532). This county was selected for this study because of the range in soil conditions and the availability of a modern soil survey report to aid in the evaluation of ERTS data.

The objective of this study was to examine black and white images of each of the four MSS bands of data and to evaluate each of the bands for its utility in preparing a soil association map of Lynn County. Photointerpretation techniques were used to analyze and compare the images of each of the four bands of MSS data.

Initially the most conspicuous and readily identifiable cultural and soil features were examined and comparisons made between individual features in each of the four bands. Water, rangeland boundaries, and rough broken land were the most conspicuous and easily separable features. Major highways, railways where they adjoined highways, drainage patterns, playas, and the more distinctive soil associations were easily identified with varying degrees of completeness and accuracy. However, there were marked differences in the clarity of the ERTS MSS bands. Ranked from most to least useful were bands 7, 4, 6, and 5. The contrast in the range from light to dark gray in bands 6 and 5 was too great to distinguish more than water and rangeland boundaries. Band 4 was used to supplement band 7 in a few areas where it was difficult to distinguish (1) drainageways and rough broken land in a rangeland area in the southeastern corner of the county, and (2) playas and the slightly sloping and eroded, lighter colored soils surrounding the depressions from the darker colored soils of the divides. This latter distinction was particularly difficult in the northwestern corner of the county.

As the interpreter was unfamiliar with the Lynn County area, it was necessary to consult maps and reports to visualize the physiography, topography, geology, land use, and cultural features of the region. The Soil Survey Report of Lynn County was studied to determine the external and internal characteristics of the soils and their classification to make predictions as to their separability by interpreting ERTS imagery.

The water and miscellaneous land types, cultural features, and soils were tabulated and arranged in the order in which they were expected to be interpretable. After the preparation of this array, the lakes were identified and delineated; sloping and rough broken land surrounding the deep set lakes was delineated, and stream dissection that was identifiable was mapped. In this setting it was then possible to identify certain playas and the relation of the soils to the topography. North-south extending lakes such as Tahoka Lake were used to determine the north-south scale. The east-west distance between lakes such as Mound, Double, and Tahoka were used to establish the east-west scale.

The interpreter then worked westward from Tahoka Lake to Mound Lake, identifying the various features and delineating them as lakes, playas, and land use lines. In this way it was possible to locate the western county line at Mound Lake and then work counter clockwise around the county boundary. The southeast corner of the county was located with respect to the intermittant drainage and the rough broken land surrounding Moores Canyon along the Brazos River. Some features such as Potter soils were not recognizable or separable on ERTS imagery, but could be related generally to other features such as permanent pastures or rangelands.

Only fragments of major highways were identifiable, and these were used and projected through the county as a means of separating the surrounding soils. The dark colored soils, classified as Mollisols, were most difficult to identify in the northern fifth of the county where the imagery was especially dark, lacking in contrast, and the area was known to have numerous playas interspersed through it. The playas were so numerous that it was difficult to identify key ones for landscape interpretation. Playas were commonly surrounded by light colored areas (highly reflective in bands 4 and 5) or rings of light colored soils which normally indicate erosion. In this case it is believed possible that the soils may be too lightly colored to be classified as Mollisols.

In certain areas around East and West Double Lakes there is a mixture of light and dark colored patterns which reflect the intricate and inseparable mixture of light and dark soils. In such areas it was essentially impossible to establish soil boundaries by visual interpretation of ERTS imagery. Among the dark colored soils, it was exceedingly difficult to detect significant image differences by which they could be delineated.

In concluding this study of visual interpretation of ERTS multispectral imagery for mapping soils, it should be emphasized that the interpretation and identification of different soils would have been essentially impossible without the aid of a relatively recent soil survey report. The quality and limitations of the map produced from ERTS imagery should be evaluated by field examination.

ERTS multispectral data are being used in a study of the soils of Lubbock, Lamb, and Crosby Counties. In the case of these areas both machine-processing and photointerpretation techniques are being employed. Results from these studies are presented elsewhere in this report.

c. Crop Identification Study

The following paper was presented at the Symposium on Significant Results Obtained from Earth Resouces Technology Satellite-1 under the title "Identification and Mapping of Soils, Vegetation, and Water Resources of Lynn County, Texas by Computer Analysis of ERTS MSS Data" by Marion F. Baumgardner, Stevan J. Kristof, and James A. Henderson, Jr., 5-9 March 1973. Goddard Space Flight Center, Greenbelt, Maryland.

Introduction

This paper presents the results of the analysis and interpretation of ERTS MSS data obtained over Lynn County, Texas. The test site was chosen because it embodies a variety of problems associated with the development and management of agricultural resources in the Southern Great Plains. It is one of ten counties in a larger ERTS test site centering around Lubbock, Texas.

Description of Test Site. Lynn County is a part of the High Plains lying south of the Canadian River. Known as the Llano Estacado, it is essentially a plateau, bounded on the north, east, and west by prominent escarpments rising from stream-eroded lower lands. On the south it merges physiographically with the Edwards Plateau.

The plains surface is quite flat and, except for a few canyons, is devoid of topographic features. The surface slope is southeast averaging 1 1/2 to 2 meters per kilometer. Canyon erosion is gradually reducing the total area of the Llano by slow retreat of the bounding escarpments. Stream drainage of the Llano surface is imperfectly developed. There are only a few widely-spaced minor valleys. These valleys typically have alluviated and unchannelled floors and are almost devoid of tributaries. Only during rare periods of excessive rainfall does water flow through the Llano valleys.

The most remarkable topographic and hydrologic characteristics of the Llano are the great number of shallow depressions, ranging in size from a few hectares to more than 15 km^2. These "prairie potholes", "playas", or "salinas" accumulate drainage from local watershed areas that range in area from less than 100 hectares to several hundreds of hectares. Most of the playas contain ephemeral, fresh to alkaline water during part of the year. The form of the depressions varies, with topography of the bottom and sides depending on the character of the formations in which the depressions are formed. Water loss from the playas is by evaporation and seepage towards recharge of the water table.

The principal income of Lynn County is derived from agriculture and ranching. The major problems associated with the development and management of the agricultural and rangeland resources of the county are drought, wind erosion, hailstorms, soil productivity, and invasion of rangelands by mesquite (Prosopis glandulosa and Strombocarpa odorata). The purpose of this study is to examine the utility of ERTS MSS data in identifying, characterizing and mapping the soil, vegetation and water resources in this semiarid region. Successful application of remote sensing and machine-processing techniques to arid and semiarid land management problems will provide valuable new tools for the one-third of the world's lands lying in arid-semiarid regions.

Data Acquisition and Analysis

Ground Observation Data Collection. Ground observation data for Lynn County were collected by residents of the area. Six Lynn County farmers who were interested in cooperating in this experiment were requested to make ground observations along segments (6-10 kilometers) of county roads at the time of each ERTS overpass. Fields along each segment were numbered and information on crop type, crop conditions, soil conditions, planting pattern, row direction, and ground cover were recorded. These data from segments well distributed over the county were used in selecting training and test areas for the supervised classifications.

Aircraft Underflight Data. On 12 September 1972 an aircraft mission obtained data over the center of Lynn County on a single north-south pass at an altitude of 6,000 m. Color infrared photographs from this mission were very useful in the interpretation of patterns of rangelands shown in the classification from the computer-analysis of ERTS MSS data.

ERTS Data Analyzed. Multispectral scanner data from ERTS passes over Lynn County on 9 October, 14 November, and 2 December 1972 were used in this study.

Analysis Procedure. The LARSYS software system is a package of computer programs which have been designed to analyze and display remotely sensed multispectral data. Five major processing algorithms were used in this study: (1) CLUSTER, (2) STATISTICS, (3) CLASSIFYPOINTS, (4) PRINTRESULTS, and (5) PHOTO. The CLUSTER processor is an unsupervised classifier that groups data vectors into spectrally distinct classes. Mean vectors and covariance matrices are calculated by the STATISTICS processor and are then used in the CLASSIFYPOINTS processor which performs a maximum likelihood Gaussian classification on a point-by-point basis over the entire area. Results from the analysis are then displayed using: (1) the PRINTRESULTS processor to make alphanumeric maps; and (2) the PHOTO processor to display the results on the Digital Image Display System.

The Digital Image Display System receives an image from a System 360 computer, stores these data in a video buffer, and displays the image in a raster scanning mode on a standard television screen. An interactive capability to edit, annotate, or modify the image is provided through a light pen and a program function keyboard. An additional photographic copying capability is also provided.

Results and Discussion

Ground observation data and aircraft underflight photography were used in the analysis and interpretation of the ERTS measurements. Ground observations were made by six cooperating farmers. Each farmer identified crops and described soil and crop conditions in fields on each side of a 10-13 kilometer segment of a county road. Figure 21 (a classification of ERTS data) represents one of the observation segments. "A" is an area of cultivated fields. "B" is an area of rangeland in which the mesquite has been successfully eradicated. Projection of the observation segments on the Digital Image Display System made it possible to identify and locate the address of each ground observation site on the digital MSS data tapes.

Soils Resources. Although a large percentage of the land surface of Lynn County was covered with natural vegetation and crop residues at the time of the ERTS overpasses reported herein, broad soils patterns are revealed in the ERTS multispectral data. Figure 22 is an MSS band 2 (0.6-0.7μm) gray scale image of the test site on 14 November. The dark areas along the north and east of the image (A) represent deep moderately permeable loams and clay loams; the small, highly reflective area (B) contains deep permeable fine sands. The highly reflective soils in the southwest and west of the county (C) are deep, moderately permeable fine sandy loams. Results to date suggest that well chosen training sets for the analysis of ERTS MSS data obtained at a time when a maximum percentage of soil is without cover could greatly refine and improve the capability to delineate the soils boundaries of Lynn County.

Vegetation Resources. The two major land uses in Lynn County are agriculture and ranching. Of the total agricultural

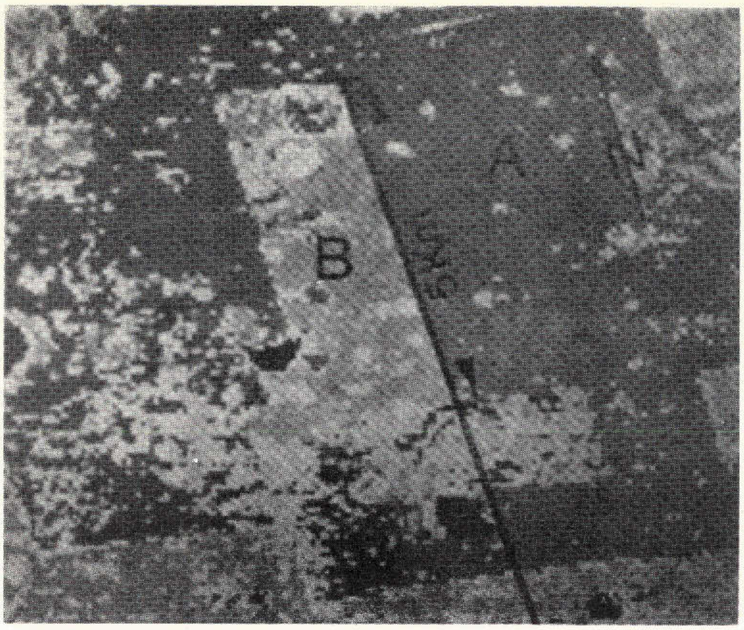

Figure 21. Classification of area around a ground observation site.

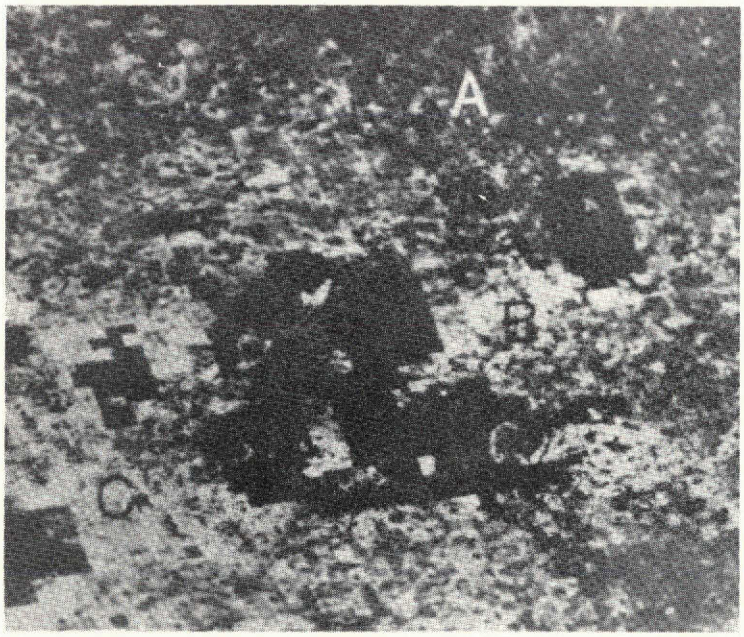

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Figure 22. Gray scale image of Lynn County, Texas. ERTS MSS band 5 (0.6-0.7μm), 14 November 1972.

land there is little under irrigation. Approximately 58% of the county was in cotton in 1972. Other cultivated crops include grain sorghum and forage sorghum. Vegetation of rangelands consists primarily of natural grasses and mesquite.

Ground observation data obtained on 9 October were used for training and test sets for the computer-implemented analysis of 9 October, 14 November, and 2 December ERTS data. Classifications of row crops, pasture, fallow, and water were obtained for each of these dates (Figures 23, 24, and 25). Examination of these classifications reveals that field boundaries and homogeneity of fields are much better for 9 October. With the use of temporal overlay techniques a classification was obtained using the best combination of four MSS bands from the three dates (9 October, 14 November, 2 December). The four bands selected to give the best classification of row crops, pasture, fallow, and water were bands 5 (0.6-0.7μm) and 7 (0.8-1.1μm) for 9 October and 14 November (Figure 26).

The highest percent correct recognition was 89.6% for the 9 October classification. The accuracy declined for the 14 November and 2 December data. For the temporal overlay classification (Figure 26) the accuracy approached that of the classification accuracy for the 9 October data.

It was not expected that this late in the growing season temporal overlay would improve classification results. A killing frost early in November, excessive autumn rains, and late summer weed growth contributed to much confusion in classification results from the November and December data. Experience in identification of summer annuals indicates that the most significant contributions of temporal overlay will be made during the active growing season prior to senescence.

Water Resources. Since water has very low reflectance in the near infrared wavelengths (ERTS spectral bands 6 and 7), it was easy to separate and map playas and reservoirs containing water. Water was separated spectrally from all other categories for three ERTS overpass dates. It was found that many of the playas containing water on 9 October contained no water on 14 November; many with no water on 14 November had water on 2 December.

Examination of the precipitation records revealed a record high rainfall for August and September. At the time of the 9 October ERTS overpass essentially all playas were full (Figure 27). During the three weeks prior to the 14 November overpass very little rain had fallen in Lynn County. Water in the playas had been partially or completely depleted by evaporation and/or seepage to groundwater recharge. The period from 12 November to 2 December (ERTS overpass) was characterized

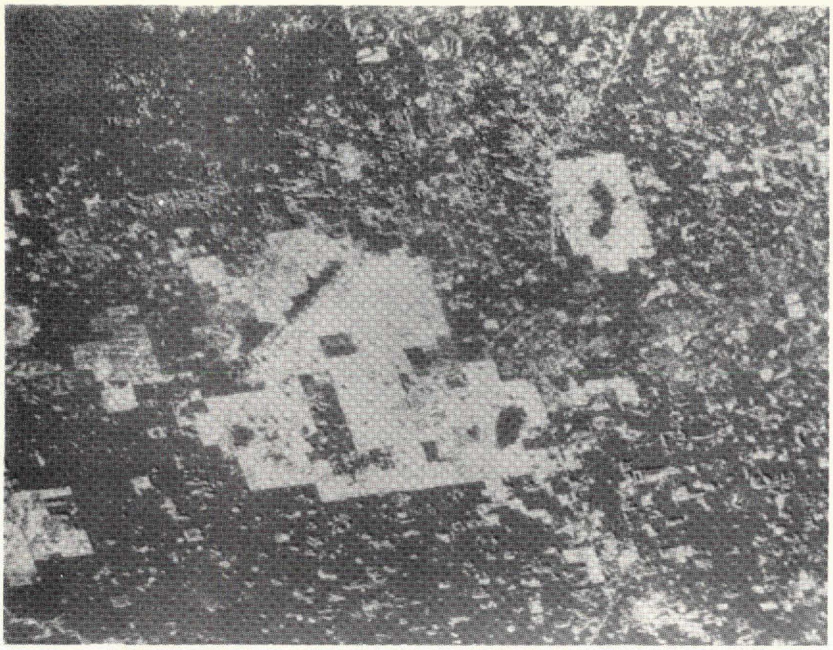

Figure 23. Four spectral classes representing row crops, pasture, fallow, and water. ERTS data--9 Oct. 1972.

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Figure 24. Four spectral classes representing row crops, pasture, fallow and water. ERTS data-- 14 Nov. 1972.

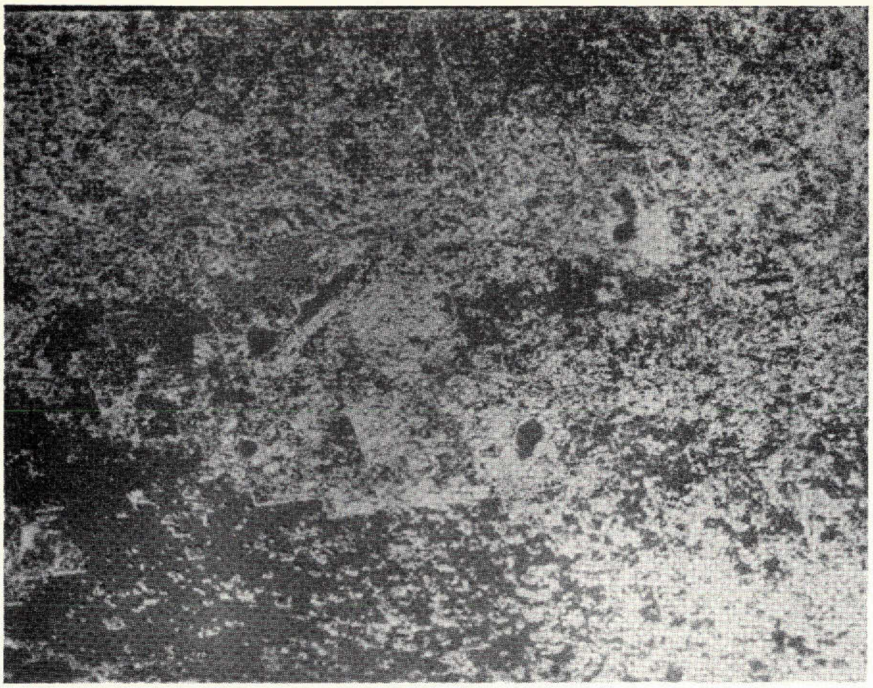

Figure 25. Four spectral classes representing row crops, pasture, fallow, and water. ERTS data-- 2 Dec. 1972.

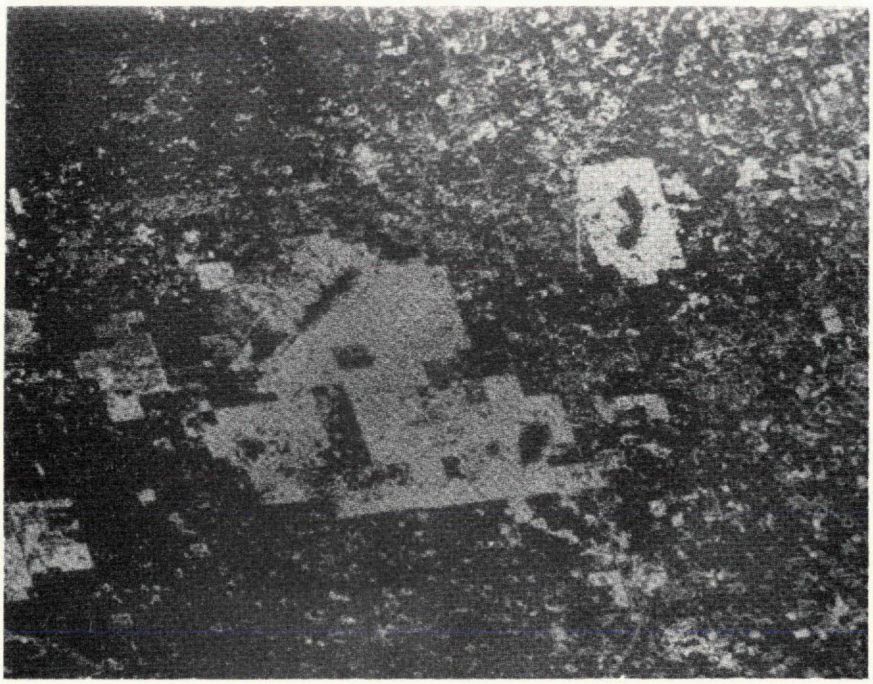

Figure 26. Four spectral classes representing row crops, pasture, fallow, and water. From overlay of ERTS MSS bands 5 and 7 on 9 Oct. and 14 Nov. 1972.

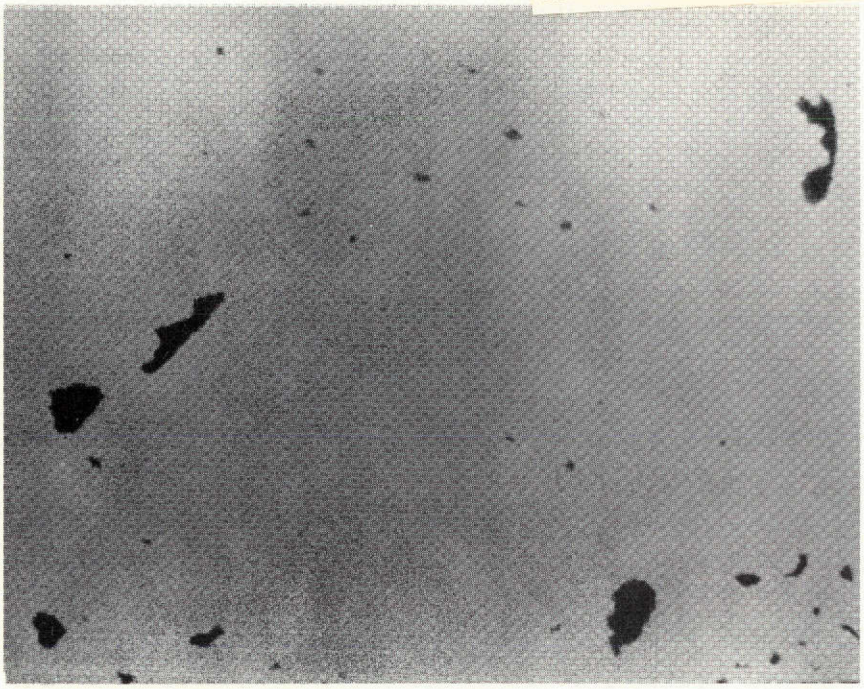

Figure 27. Two spectral classes representing water and other in Lynn County, Texas. ERTS data--9 October 1972.

by cloudy days, high humidity and several light rains. The ERTS data for 2 December reveals water in many playas which had no water in mid-November (Table 9).

Temporal Overlay. Temporal overlay capabilities provide a significant advance in the machine-processing of multispectral scanner data. It is no longer necessary to go through the tedious exercise of locating ground observation sites on the digital data from each ERTS overpass. Once the address of a ground observation site has been located on a digital tape from any ERTS overpass, the overlay technique can be used to locate the same address on a digital tape of MSS data from any other ERTS pass over the same area.

The temporal overlay technique also adds a valuable dimension for identifying and mapping changes in vegetation, water, and other dynamic surface features.

Table 9. Estimated Changes in Water Surface Area.

Date	Points	Hectares
9 Oct.	4374	1924
14 Nov.	3735	1643
2 Dec.	5120	2252

Total Area: 197683 hectares

5. GROUND OBSERVATION COLLECTION SYSTEM FOR LUBBOCK REGIONAL TEST SITE

Ground observations were obtained during the 1972 and 1973 growing season by volunteer observers. Originally six farmers in each of the ten counties that compose the Lubbock Regional Test Site volunteered to collect ground information. Each farmer was asked to take observations along a 6-10 kilometer segment of road with which they were familiar. At the beginning of each growing season, the ground observers submitted maps of their road segments which showed the numbers they had assigned to individual fields and their sizes and locations (See Appendix A). Before each ERTS overpass, ground observation forms, a return envelope, and other information which would enable the ground observer to collect the best information possible were mailed to each observer. At the time of each ERTS pass, the ground observers were requested to make observations along their assigned road segments and mail the completed observation forms to LARS.

At the beginning of the ERTS Experiment approximately 60 people volunteered to collect ground observations. During the experiment, almost one half of the volunteers stopped collecting ground observations, and we ended the project with approximately 33 ground observers. Although this is a considerable drop in observations, those we received during the latter part of the project were as useful in our analysis as the observations we received from the original 60 observers.

In addition to the regular system of ground observations described above which accompany each ERTS pass, a ground observation mission was carried out by two members of the LARS staff for the 6 July 1973 ERTS pass. Observations were confined to three counties (Hale, Lubbock, and Lynn) and were made in two ways: (1) completing ground observation forms for selected fields, and (2) taking low altitude photos of those fields. Three north-south transects across Hale, Lubbock and Lynn Counties were chosen for making ground observations. Detailed observations were made at road intersections. These intersections are at an interval of 2 to 4 miles to give a well distributed set of ground observations covering the three counties. At each intersection, observations were recorded for 4 fields. The second phase of the ground observation mission was a low altitude flight over the selected intersections and other areas of interest. The photos taken during this flight along with the detailed ground observations provided the researcher with an accurate representation of the crop and soil conditions at the time of the 6 July 1973 ERTS pass. The location of ground information in Lubbock County is given in Figure 12.

Using volunteer ground observers to collect ground information has proven very beneficial to this project. In the future, however, we would suggest several changes to the procedure used in this study. With further experience in the properties (resolution and sensitivity) of satellite data, areas chosen for observations can be selected with consideration given to both its usefulness and ease of location in the data. Observation areas should be selected so that they are representative of the study area and are associated with easily located features (roads, airports, urban areas, distinctive permanent field patterns, etc.).

After areas to be observed have been located, the observers should be given an introduction to the analysis of satellite data. This introduction should include, among other items, a description of the smallest functional field size (the smallest size field that can be routinely located and/or analyzed). Also each observer should be given a map on which to outline and number the fields to be observed during the project.

If these suggestions are implemented, all ground observations will be in a form readily useable without containing a great deal of unusable detail. This should shorten the analysis time while retaining as much of the pertinent information as possible.

B. BOONE COUNTY, INDIANA ANALYSIS

Row crop production is of immense importance to the world. The grain from two of these crops, corn and soybeans, has an enormous influence on many world markets. Numerous areas of the earth are incapable of producing these precious crops. Therefore, it is advantageous to know the approximate area supporting these crops and their projected yield several months before harvest. This knowledge could aid in planning more efficient domestic use and more accurately determine grain available for export.

Five land use cover types were identified in the initial investigation of a selected county within the corn belt region. The delineation of land under cultivation is the principle used to distinguish agricultural land from non-agricultural land. This study was conducted in Boone County in west-central Indiana. The southeast corner of this county adjoins Marion County, the location of the state capital, Indianapolis. A frame of multispectral scanner data (Scene I.D. 1321-15593) was obtained from the Earth Resources Technology Satellite (ERTS) on 9 June 1973. The study area was considered to be approximately 108,000 hectares. However, an area twice this size was used to identify landmarks to aid the locating of county corners.

A computer-driven digital image display system was used to locate physical features that would aid the location of county boundaries. Such features as towns, interstate highways, river and drainage systems, railroads, small bodies of water and bare soil within field patterns were identified with the aid of county highway maps and county soil survey maps (1970). The location of these training areas were punched using an option in the IMAGEDISPLAY processor.

The analysis was based on the assumption that row crops are represented spectrally as bare soil on the 9 June data. To substantiate this assumption the following analysis was undertaken. Gray scale maps of the Boone County area were requested from the geometrically uncorrected data in channels 2 and 4. The features obtained from the IMAGEDISPLAY function were plotted on these maps. Physical features, such as drainage systems and highways, were used to pick ground control samples. These samples were clustered into spectrally separable classes.

With these ground control samples the computer was used to histogram and print statistics for each of these samples. After refining these samples, the computer was used to categorize the five classes. The PRINTRESULTS function was used to test the training accuracy of the ground control samples. The training class performance was 98.7% overall, with the test field accuracy being 97.7% correct overall. Using the generated statistics deck, that portion of the county including the corners was classified and maps produced. These maps were used to locate the precise boundaries of Boone County. The county was then geometrically straightened.

Figure 28 is a photographic representation of this land use classification of Boone County. These results were compared to estimates from the Agricultural Statistics Department at Purdue University. The estimates were based on the 1972 growing season with an "x" percent increase in row crops for the 1973 growing season in Indiana (where x may reach 10%). The final report for 1973 from the Agricultural Statistics Department was not yet available for comparisons.

Row crop delineation seems to be adequately identified from the bare soil land classification from early June multi-spectral ERTS imagery over Indiana. This detection of row crops may be applied to the entire corn belt to approximate the areas put into these crops. These kinds of data can be very useful early in the growing season; it could provide means of eliminating surplus grain without jeopardizing the nation's economy.

To separate soybeans from corn would require similar studies at a later date. Additional soybeans that are planted after wheat is harvested could be delineated from ERTS data based on this bare soil-row crop spectral relationship.

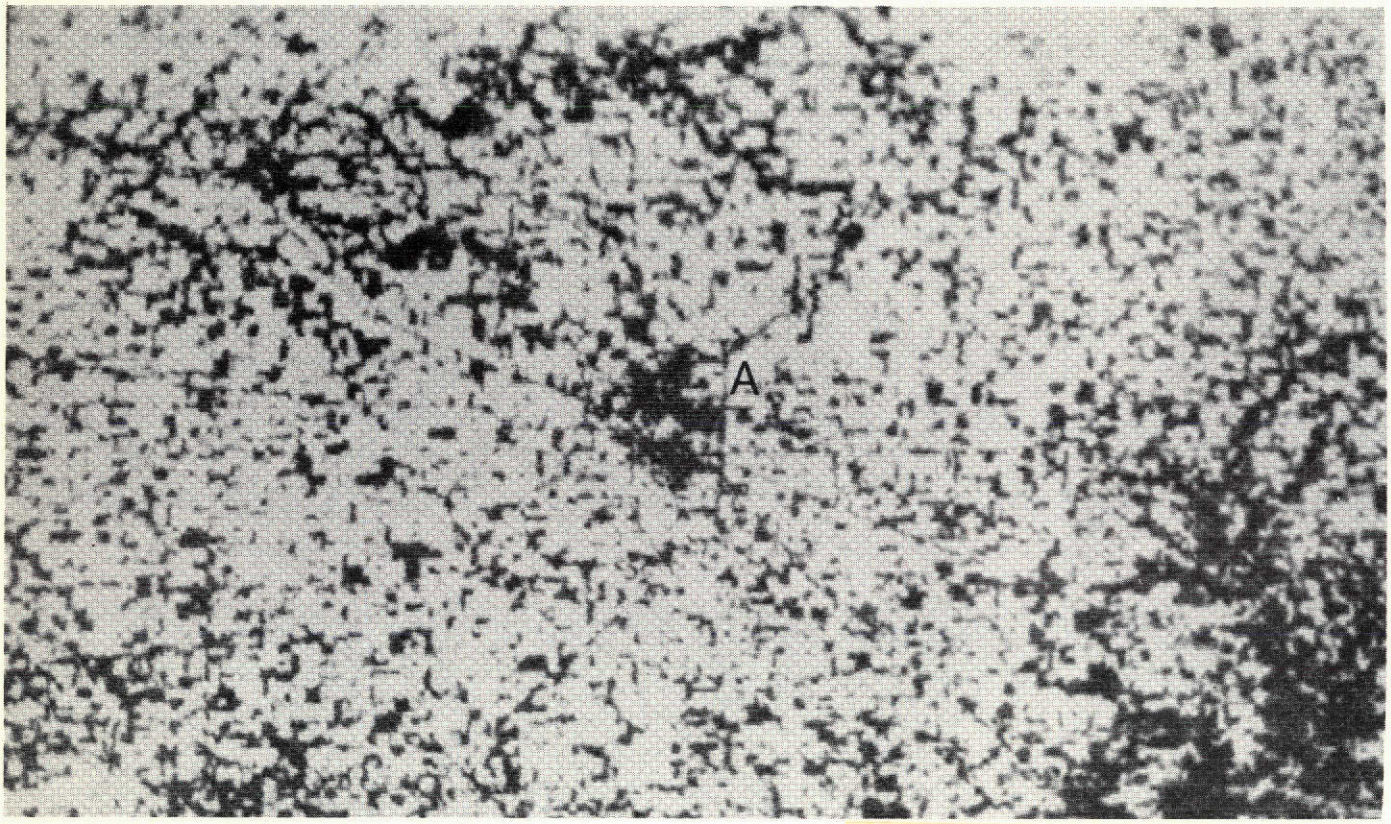

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Figure 28. Classification of Boone County, Indiana from ERTS-1 MSS Data Collected on 9 June 1973.

White - bare soil
Gray - green vegetation
Black - forest
A - Lebanon

C. GREELEY COUNTY, KANSAS ANALYSIS

Hard red winter wheat (Triticum vulgare) is the principal crop in Greeley County, Kansas. This area in western Kansas is typical of much of the winter wheat belt of the United States. ERTS-1 digital data obtained on 19 June 1973 were analyzed to separate wheat from other cover types and to measure the area in wheat.

On 14 May 1973 color and color infrared photography was obtained by a NASA aircraft at an altitude of 9500 m along a north-south flightline centered over Greeley County. By conventional photointerpretation of the color infrared photography three cover types were identified: wheat, fallow (bare soil) and permanent pasture. Training sets representing each of these three cover types were selected.

Using a clustering algorithm the ERTS-1 data for the area along the aircraft flightline were separated into eight spectrally separable classes in order to enchance the field boundaries. It was then possible to locate in the ERTS data the training fields selected from the aerial photography. A supervised algorithm was then used to classify the entire county into three categories: wheat, fallow, and pasture (Figure 29). A set of test fields was selected from the aerial photography and used to evaluate the classification results. Later, the computer classification results of several fields were verified by the cooperative agricultural extension agent in Greeley County. The classification accuracy is recorded in Table .

Table 10. Results of Computer Classification of ERTS-1 MSS Data, Greeley County, Kansas, 19 June 1973.

Class	% Correct Recognition of Tested Fields*
Pasture	96.1
Wheat	97.0
Fallow	97.9

*From underflight photography and limited ground observations

From the classification results the area of wheat in Greeley County was then calculated, and the results were compared with estimates made by the Statistical Reporting Service (U.S. Department of Agriculture). These comparisons are presented in Table 11.

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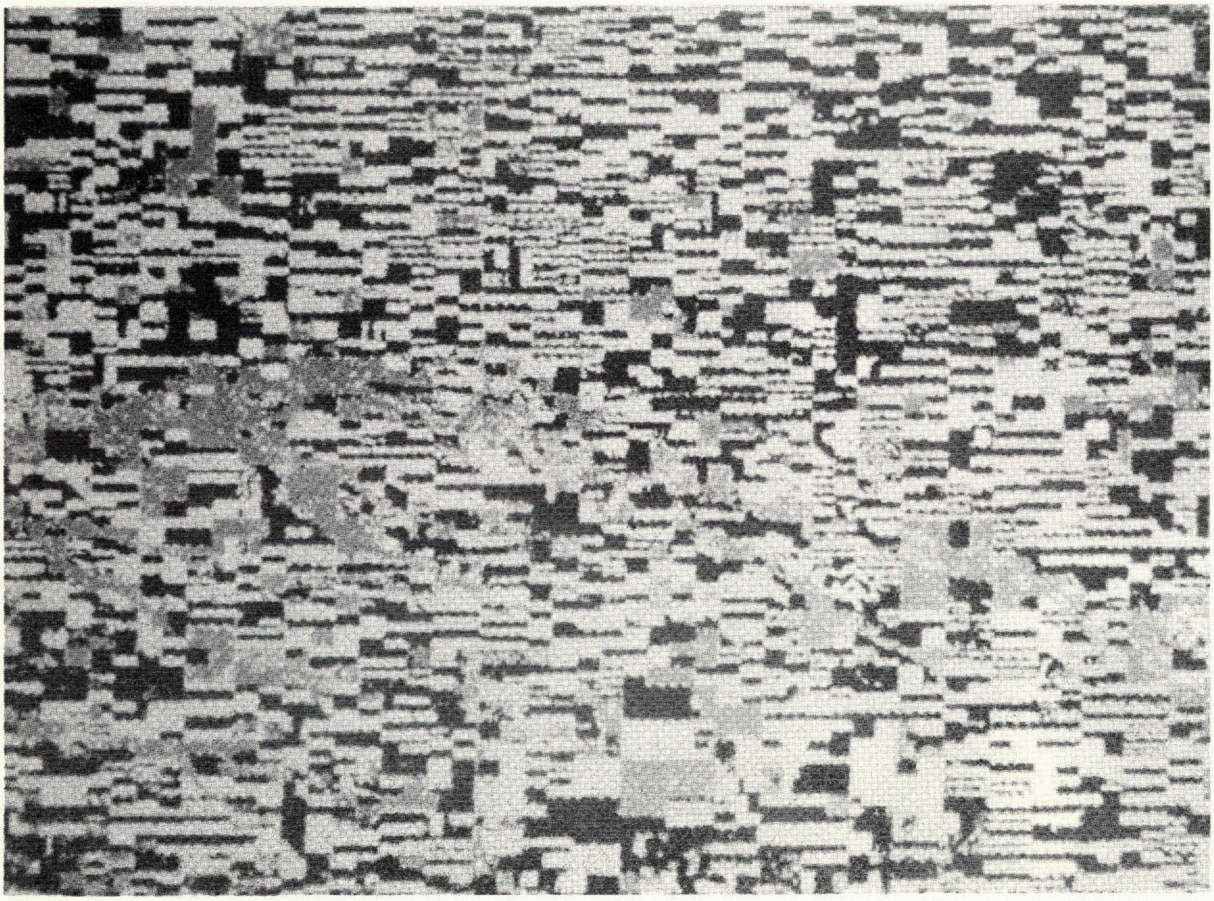

Figure 29. Classification of Greeley County, Kansas from ERTS MSS data collected 17 June 1973.

White - Wheat   Gray - Permanent Pasture
Black - Fallow Land

Table 11. 1973 Wheat Area Estimates for Greeley County, Kansas.

Source of Estimate	Hectares
SRS (USDA)	73,000 ± 5%
ERTS	77,000

D. HUMBOLDT COUNTY, IOWA ANALYSIS

Every year the Statistical Reporting Service (SRS) and the Agricultural Stabilization and Conservation Service (ASCS) monitor crop yields by using a randomized subsampling technique which samples relatively small portions of the actual area. These estimates are generally adequate. The real purpose of this estimation of crops is to understand better the supply situation for grains in order to allocate supplies properly. Current procedures for estimation of crops take a lot of time and a more rapid system would be desirable.

The purpose of this study was to investigate the ability to estimate agricultural cover types in an area where a high percentage of the crops are corn and soybeans.

ERTS data were collected over Humboldt County, Iowa on 26 August 1973 (139916320) and analyzed to study the agricultural diversity of the county and to estimate the area of land in corn and soybeans for the current crop year.

Humboldt County is in the north-central part of Iowa. It has a total land area of 432 square miles (approximately 110,000 hectares). The county seat, Dakota City, is approximately 90 air miles north-northwest of Des Moines, the State capital. The largest city in the county is Humboldt, which is located just to the west of and adjoining Dakota City. Humboldt County is largely agricultural. Most of the soils are suitable for corn and other row crops.

Analysis began with location of the county within the ERTS frame and the displaying of the county on the digital display system. Using the ratio program, training classes were used as input to the following processors in LARSYS Version III: *PICTUREPRINT, *STATISTICS, *SEPARABILITY, *CLASSIFYPOINTS, *PRINTRESULTS. The classification results were displayed and photographed.

The results of analysis are listed in Table 12 for comparison with observations from the previous years of 1954 and 1972. The 1973 figures for estimation of crop types and crop yields were not yet available in February 1974 when the study was concluded.

The trend expressed from 1954 to 1972 was an increase in land occupied by corn and soybeans and a decrease in land in other crops. In 1973, it is postulated that there would be another increase in lands in corn and soybeans; because these cash grain crops were returning higher profits in 1972 and also because there were relaxed governmental restrictions on land in cash grains.

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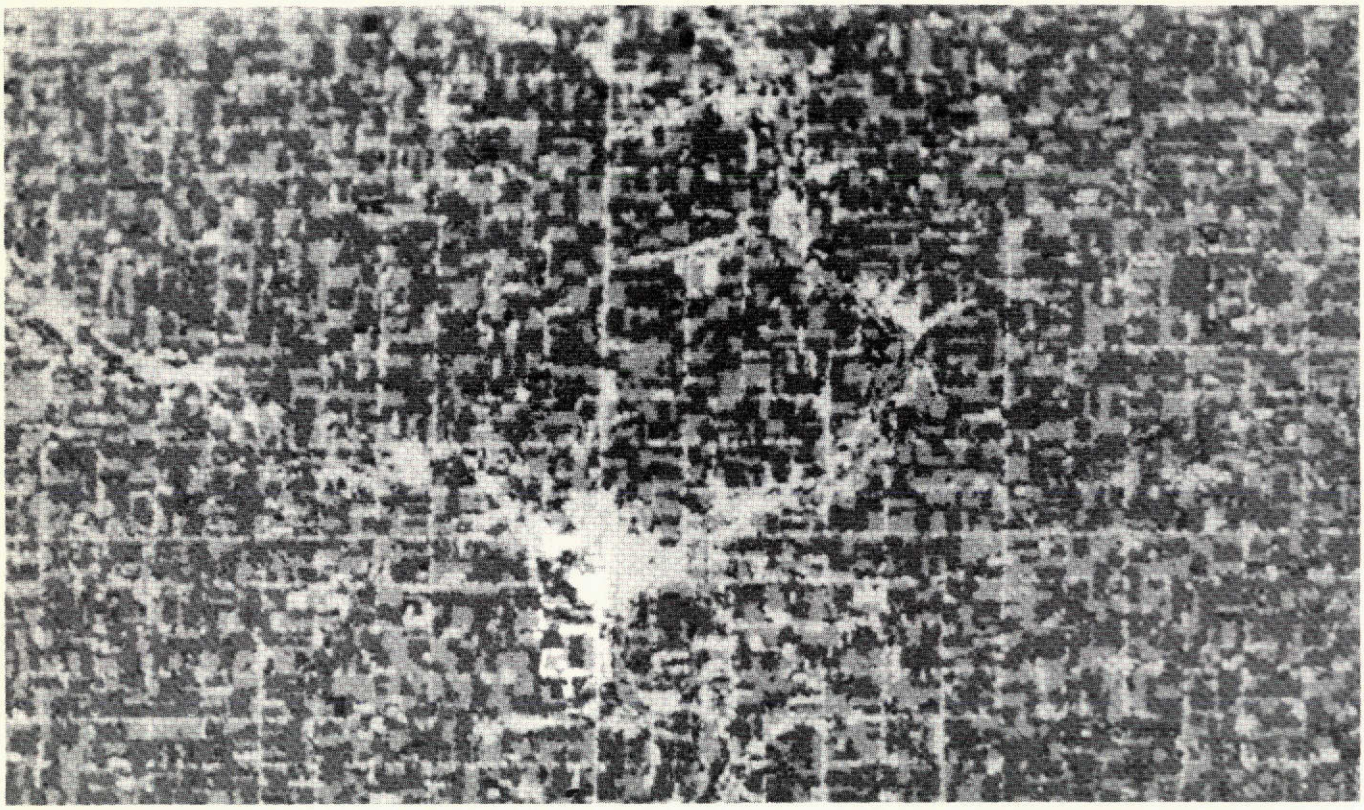

Figure 30. Photo from the Digital Display of a Classification of Humboldt County, Iowa Using Data Collected 26 August 1973.

Table 12. Compilation of SRS and Study Area Estimates for Major Crop Types in Humboldt County, Iowa.

	From SRS Estimates ($\pm 5\%$) 1954 (ha)	1972 (ha)	From 1973 ERTS Data (ha)
Corn	38,000	42,000	47,000
Soybeans	14,800	35,000	42,100
Other	57,000	33,000	21,500

Therefore, it appears that the increase detected in this study is real if the trends continue as they have in the past. This study demonstrates the potential usefulness of satellite imagery. It seems that current, satisfactory imagery should aid in areal crop estimation for corn and soybeans.

The selection of satellite imagery is an important factor. This frame of imagery was very useful because of its definition, and distinction of roads and towns was quite easy. Therefore, location of the areas of interest was precise. One of the major difficulties with using satellite imagery is in the location of test sites. This problem can be diminished by careful screening of the imagery and selection of the most usable data.

E. MCPHERSON COUNTY, NEBRASKA ANALYSIS

The following manuscript, "Machine-Aided Analysis of Land Use-Land Form Relations from ERTS-1 MSS Imagery, Sand Hills Region, Nebraska", by S. Sinnock, W. N. Melhorn, and O. L. Montgomery, will be presented at the University of Tennessee Space Institute Conference on Remote Sensing, 25-27 March 1974.

1. INTRODUCTION

The results described in this paper are an outgrowth of geomorphological studies of the Western states conducted during the past two years at LARS/Purdue. In attempting to classify landforms through computer-aided spectral signature analysis performed on ERTS-1 MSS data, it was soon realized that vegetation, soil, and hydrologic patterns are paramount in determining the spectral characteristics of the earth's surface forms. To effectively implement machine-aided landform classification, it is necessary to develop an understanding of spectral relationships among these surficial variables. A portion of the Sand Hills region of Nebraska was chosen for study because it has a relatively simple indigenous ecosystem, with surface variables that are amenable to automatic data processing. The interdependence of soils and vegetation, and their genetic relationship to groundwater make the Sand Hills a prime area for case study in machine-aided spectral analysis. The human portion of the ecosystem is intertwined with the physical variables; thus, land use studies are another, albeit peripheral, aspect of this report.

2. DESCRIPTION OF THE REGION

The Nebraska Sand Hills are one of the most varied and extensive prairie lands in North America, and undoubtedly represent the greatest single areal accumulation of aeolian materials on the continent. Hayden* in 1871 estimated the total area as 20,000 square miles, a figure which recurs in modern literature. The region is encompassed in the area bounded by the Niobrara River on the north and the Platte River on the south. The Sand Hills are composed of quartzose sand comingled with loess derived from continental glacial deposits of northeastern Nebraska, as described by Thornbury and Condra. The hills extend eastward from the 103rd Meridian to near the 99th Meridian; farther east and southeast they pass into loessial hills which are derived in part from finer clay and silt deflated leeward from the Sand Hills. McPherson County, the principal locale of our study, is located in the south-central part of the region described (Figure 31).

*References mentioned in this paper will be cited in the Selected Bibliography section.

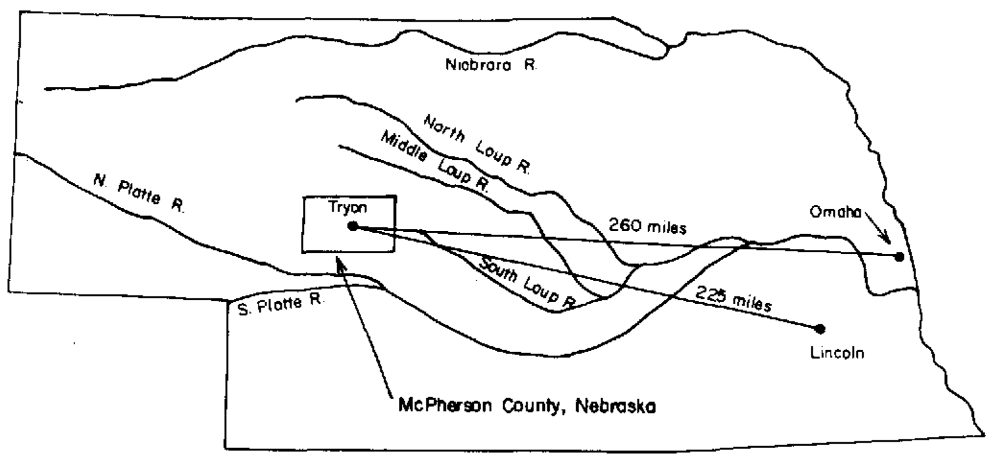

Figure 31. Location Map of McPherson County, Nebraska.

The geology is relatively simple; 6 to 120 m of Quaternary and Tertiary sands rest on the Ogalalla Formation and older Tertiary rocks. The size and height of dune complexes varies within the region, but in McPherson County they range upwards to 25 km long, 1/2 km wide, and 30 to 90 m high. Sniegocki has described an air view of this region of sand dunes and intervening sand-floored valleys as resembling the surface of a billowy sea. The dunes are generally asymmetric, with steeper sides on the north and east, a response to prevailing westerly winds. The tops and sides of dunes have commonly been hollowed out by wind action, creating crater-like features called "blowouts". Interspersed in hollows between dunes are basins containing ephemeral groundwater lakes and marshes, though these are scarcer in McPherson County than elsewhere farther west. Blowouts show all stages of graduation from almost constant movement to total stabilization. The graduation is clearly evident in terms of depth and outline of blowouts, and abundance of encroaching vegetation. Temporal change in stabilization by good range management, and perhaps changing climate, is evident from Aughey:

> Formerly these "barren holes" were abundant... now the body of them are grown over with grass, and new ones in process of forming are only met with at longer intervals.

It is probable, therefore, that the frequency of new blowouts is less today than it was a century ago.

The annual rainfall equivalent is about 500 mm, or climatologically subhumid. Soil moisture is available to climax and invader grasses which blanket the area. McPherson County, as elsewhere in the Sand Hills, is characterized by high evaporation rates, rapid infiltration, internal drainage, and lack of surface streams. North Fork Birdwood Creek and Squaw Creek are the only significant surface streams in the county. Annual recharge to subsurface aquifers is estimated at 120 mm/yr. and loss by lateral seepage to subirrigated hay meadows as 75 mm/yr. The remaining moisture is probably lost to evapotranspiration. The piezometric surface rises westward across the county, coincident with an increasing gradient. However, eastward slope in the water table is greater than surface declension; thus, the groundwater surface is more than 30 m deep in the east, but as shallow as 5 m at the western side of the county. Physiographically, this change is evidenced by the appearance of permanent lakes in the west where the water table intersects the land surface in depressions, whereas there is no surface water in the eastern two-thirds of the county.

Native grass is the predominant vegetation, and about 97% of the county is in rangeland or native hay pasture. The great variation of grasses includes elements of tall, short, and bunch grass prairie. The grasses grow luxuriantly in the valleys, but on the higher sand hills are thin and are interspersed with small, woody plants, weeds, and prickly pear cactus. Previously tilled land tends to cover with ragweed and tumblegrass. Trees, introduced by homesteaders, thrive along the few streams, the semi-permanent lakes, and subirrigated hay meadows, and are mostly cottonwood, boxelder, willow, and hackberry.

Windblown, fine-grained sand of the Valentine soil series occupies 93% of McPherson County, under a cover of mid-high to tall range grasses. In low areas, the fluctuating water table and coincident luxurious growth of reeds, rushes, and water affine trees have contributed to more extensive soil development in the A-horizon. Gannett, Elsmere, and Dunday soil series are abundant in such depressions and adjacent to surface streams. These soils are better suited for growth of native grasses capable of being cut for hay. However, care must be taken in the spring and immediately following summer rains to avoid excessive soil damage during cutting, owing to the susceptibility of these fragile soils to disruption by farm equipment. Breakdown of soil structure promotes deflation and resultant blowout development.

Areas of Valentine soils are best utilized for grazing, with range conditions varying from poor to good. Areas on the Gannett-Dunday-Elsmere series, formerly cultivated, are now returning to range. Blowout land, normally in plots 1 to 2 hectares in extent, occupies only 0.3% areally, and lakes occupy about 0.1%.

The Sand Hills represent an interesting story of changes in vegetation and land use within historic times. Jackson cites the reports of early visitors to the region. One description in 1797, defines the region as an area of shifting sands devoid of trees, soil, or water. A representative of the Chadron Land Office, in 1855, wrote that no grasses grew among the hills, but that lakes were hidden amid the labyrinth of dunes. However, in 1871 Hayden was able to state:

> ...this region is by no means the utterly barren waste that it is sometimes represented to be. It has been a favorite range for buffalo, and still is for antelope and deer; and, judging from their condition, the conclusion would be natural that this region could be used for stock raising.

During the 1870's, a few cattle from herds trail-driven from Texas to railheads on the Platte River escaped, wandered into the Sand Hills, and reproduced. This led to movement of cattlemen into the dune country. After passage of the Kincaid Homestead Act in 1904, prairie homesteaders entered the region in numbers and attempted to raise corn or other grain crops. However, poor soils, undependable surface water supply, and erosion by deflation caused by tillage doomed extensive row cropping. The drought of the early 1930's completed extinction of any large-scale organized farming, and the area has subsequently reverted chiefly to grassland range for feeder cattle. The scars of farming remain, however, as "go-back land" tucked in the recesses of the "choppies" or sand hills.

3. ANALYTICAL PROCEDURE

It is necessary to generate automatically spectral statistics for a range of classes representative of the total range of surface reflective characteristics to classify an area by techniques developed for the LARS/Purdue IBM 360/67 computer. The following procedure was used to implement computer classification and mapping of the Sand Hills region.

Four sets of training fields (groups of approximately 100 adjacent data elements) were selected from the four most spectrally contrasting areas on single channel non-classified computer gray scale printouts of the region (ERTS-1 Scene ID 1313-16563, CCT number 73039300, 1 June 1973). Data from each of these four training groups were separated statistically into five spectral classes by a nonsupervised algorithm. Values for the mean relative reflectivity (scale 0 = black, to 256 = white) of each class were obtained for each ERTS-1 channel from the LARSYS processor, CLUSTER.

These values were plotted as a function of ERTS-1 wavelength bands to obtain spectral plots for each of the five spectral classes in each major training group. These plots provide a means to visually inspect spectral signatures of classified surface phenomena. In this manner the spectral classes for all training groups were compared. In each case, the plots of the least reflective class and/or classes from the brighter training groups coincided with those of the most reflective class and/or classes of the next darker training groups. Overlapping classes were combined, eliminating several nonsupervised classes from consideration as distinct spectral types. From the initial set of 20 nonsupervised classes, 14 were chosen for further analysis. These 14 classes contained the complete range of spectral variance within the region (Figure 32).

Printer images were then generated to show the spatial distribution of the nonsupervised classes within each 100 data

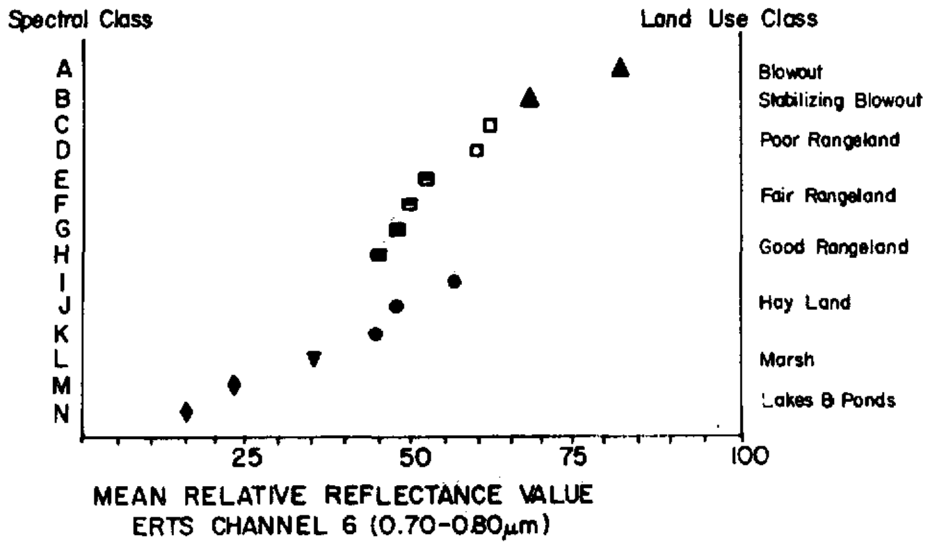

Figure 32. Coincident spectral plot showing relationships among 14 spectral classes used in this study. Relative reflectance in ERTS-1 channel 6 is plotted for each class.

element training field. Training fields of 1 to 10 data elements were relocated within the initial, larger training fields. The new training fields were selected as representative of the 14 chosen spectral classes, and produced by a supervised algorithm. This processor, STATISTICS, generated classification statistics for the 14 classes of interest.

To interpret these statistics in a meaningful manner, classes represented by the statistics must be correlated with familiar surface cover types such as soils, vegetation, lithologies, hydrologic features, etc. To achieve this correlation, an area in McPherson County of about 18,000 hectares (200 x 200 data points) was automatically classified, based on the supervised statistics. Each spectral class was then displayed on a printer image by a particular alphanumeric symbol, allowing inspection of the spatial distribution of each class. This distribution was then compared with soils distribution shown on the USDA soils map 8. Significant geographic correlation among certain spectral classes was noted. Sets of similarly distributed spectral classes, if considered as units, were found to follow closely the patterns represented on the soils map. Based on this pattern similarity, soil names were assigned to the spectral classes. Land use and vegetation type names derive from soil type. Because the Valentine soil series is represented by 6 spectral classes, land use and vegetation categories within these classes must be inferred from other information. Figure 32 shows that classes C, D, E, F, G, and H decrease in reflectance from class C to class H. The more highly reflective classes, D and C, grade into classes representative of blowouts (as determined by spatial comparison as outlined above). From these spectral characteristics it was inferred that the more highly reflective classes represented areas with a less dense vegetal cover, grading eventually into blowouts with no cover. These less densely covered classes were named "poor rangeland". The spectrally less reflective classes were accordingly called "fair" and "good" rangeland to indicate the inferred increase in grass cover. A subsequent revision of the classification statistics was performed to include a class interpreted as cropland on Gannett and Elsmere soils in the classification scheme. Thus, a combination of geographic relationships and spectral characteristics was used to infer the surface type represented by the spectral class.

4. RESULTS

The machine-aided analytic procedure outlined provides a means to rapidly reduce large amounts of data to forms more compatible with human pattern recognition capabilities. The statistical computations and refinements of the project required about one hour of central processing time.

Classification results can be automatically displayed on printer images, television screens, graphical images, or tabular matrices through the LARS computer program system (LARSYS). However, at this point the capabilities of the machine come to a halt. The machine cannot interpret its own maps, graphs, or tables. As discussed under analytical procedures naming of spectral classes is a uniquely human task based on inference, induction, and a certain degree of intuition. Because these mental processes inevitably bias the experimental framework, the objectivity of computer-assisted mapping techniques is not to be accepted as complete. This is not to say that the experimental results are invalid or inaccurate, but merely to point to the indispensible necessity of human interpretation in any mapping project, computer-assisted or otherwise.

Figure 33 is a machine-generated spectral class map of the western half of McPherson County, eastern Arthur County, and southern Hooker County (see Figure 47 for a location index of all computer maps discussed in the text; outline A of Figure 47 locates the area represented in Figure 33). The photograph is a Polaroid black and white print of the Sand Hills classification results as displayed on the photocopy unit of the LARS digital display television screen. The spectral classes have been grouped to accentuate land use and soils patterns. Each group of spectral classes was assigned a particular gray level for photography.

The lightest gray tone areas represent poor, sparsely vegetated rangeland dominated by invader and increaser grasses and shrubs. The next two darker gray tones represent improving rangeland conditions. Optimum rangeland is displayed as medium gray tone. The forage is composed predominantly of decreaser grasses such as big and little bluestem, indiangrass, etc. All classes of rangeland are developed primarily on entisols of the Valentine series. A light gray swath separating two medium gray tone areas traverses the figure from northwest to southeast. This band of poor to fair rangeland conforms to the top of a broad "whaleback" or seif dune structure. Similar large seif dunes within the Sand Hills region are oriented in the same direction, indicating a northwesterly wind direction during dune formation. The medium gray tone bands bordering the seif dunes on the northeast and southwest are located along wide swales between adjacent dunes. The best rangeland is in these broad, interdunal swales or valleys (Figures 34 and 35).

The darkest gray splotches distributed throughout the western portion of the spectral class map (Figure 33) represent lowlands in irregularly shaped depressions and along the valleys of Birdwood and Squaw Creeks. These areas are the best lands in the region for cutting of native hay. Here, the water table is near the surface and provides better growing

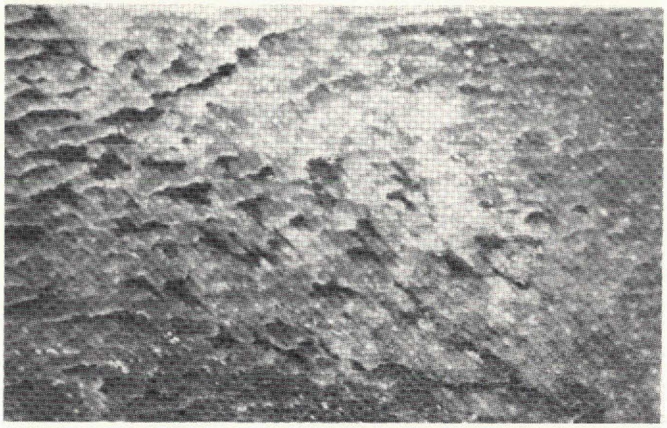

Figure 33. Spectral class computer map of Sand Hills region obtained from digital display television screen. Gray scale coding is discussed in Text. See outline A, Figure 47, for geographic location.

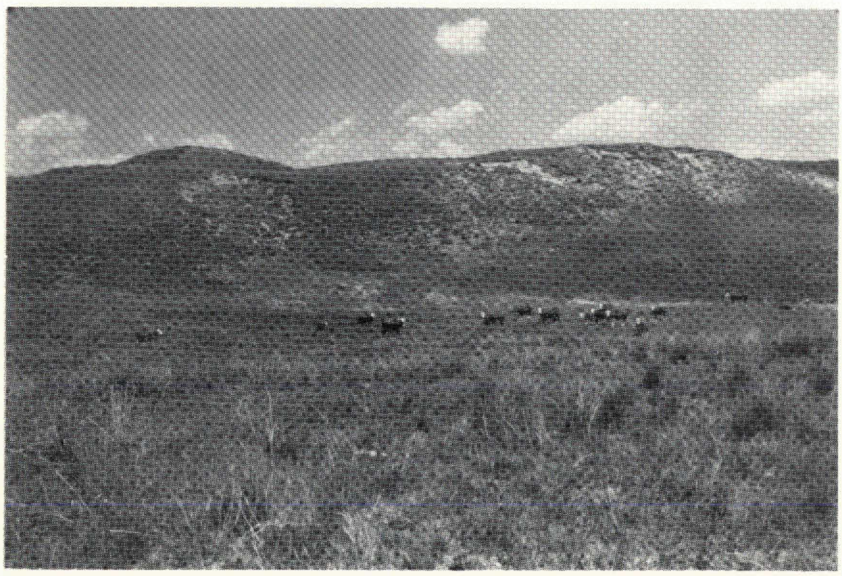

Figure 34. Rangeland in Sand Hills. Note the lush green grasses in the foreground and the sparser grasslands on the seif dune in the background. A small parabolic dune is superposed on the larger dune structure in the upper left of the picture.

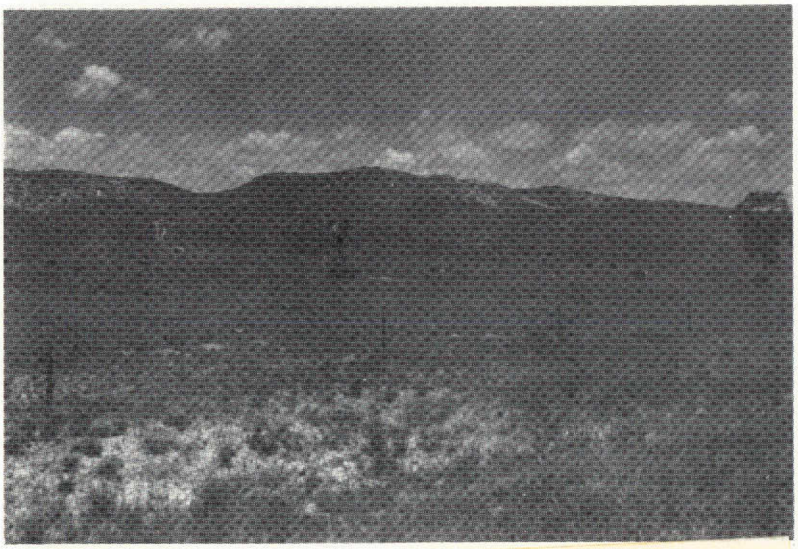

Figure 35. Good rangeland in the swales or valleys, and poor to fair rangeland on the seif dunes. Windmill driven pumps draw water to the surface for the cattle.

conditions for native grasses suitable for harvesting. The proximity of the water table to the surface is genetically related to development of the Elsmere, Dunday, and Gannett alfisols that predominate in these depressions (Figure 36). Where the water table intersects the surface lakes, ponds and marshes occur (Figure 37). These are displayed as black on Figure 33. Wetlands comprise only a small percentage of the dark gray depressional areas. For this reason, water covered areas are difficult to locate on Figure 33.

By representing each datum point with four picture elements, an enlarged portion of Figure 33 can be photographed directly from the ditial display unit. Figure 38 is such a data enhanced image; the spectral class gray scale symbols are the same as in Figure 33. This method of enlargement facilitates perception of small units of gray tone impossible to see on the smaller scale map. A further enlargement, whereby each datum point is represented by 16 picture elements is shown in Figure 39. This photograph portrays the area around Schick Lake, 15 miles west of Tryon, the county seat of McPherson County. The lake is clearly visible at the eastern end of the dumbbell-shaped dark gray lowland region in the center of the picture.

A further level of image enlargement is available to users of the LARSYS computer programs, but to obtain it the medium of display must be changed. Figure 40 is a photographically reduced printer image of approximately the same area as Figure 39. Each alphanumeric symbol on the printout represents a certain group of spectral classes, which in turn are interpreted as a particular soil type. Blank areas are blowouts, which range in size from a single datum point (1/2 hectare) to as many as 10 data points (4 ha). Soils of the Valentine series (dots) cover 83.2% of the surface represented on Figure 40. Asterisks represent the Elsmere and Dunday soil series formed in the depressions. Other lowland classes are the Gannett soils displayed by "G's", marshes by "M's", and lakes by "W's". A roughly circular area of crosses in the lower left portion of the figure is interpreted as cropland irrigated by a center-stand irrigation system. The identity of the crop type is unknown. The scale of the printer map before photographic reduction is approximately 1:24,000. Geographic distortions are inherent in the data, but can be removed by techniques developed at LARS/Purdue and elsewhere.

To facilitate interpretation of this computer printout map, an overlay outlining the major symbol groups was constructed, and is shown in Figure 41. Township and range lines, one highway, and two lake names have been added to accentuate the map's geographic character. For comparison of this map to a previously published map of the same area see Figure 42.

Figure 36. Lowland suitable for hay cutting. Note change in vegetation just beyond the fence where the slope ends and the basin begins. A few trees are in the background at the far end of the lowland.

Figure 37. Arthur Lake, a typical Sand Hills lake, in eastern Arthur County. Note the lush green vegetation in the foreground and the ring of reeds and rushes encircling the lake.

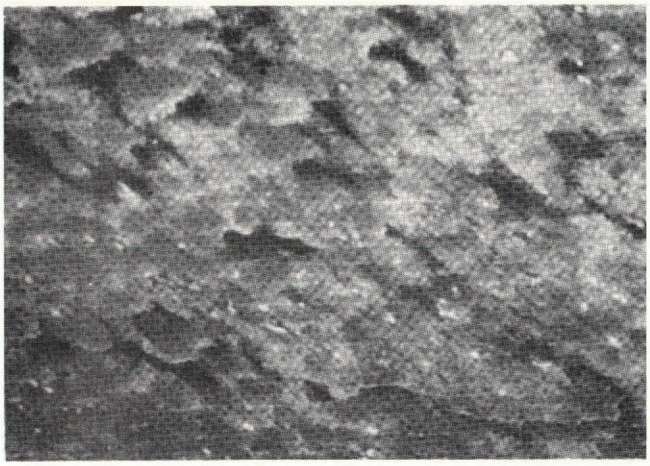

Figure 38. Computer enlargement of Figure 33. See outline B, Figure 47, for geographic location.

Figure 39. Further computer enlargement showing detail of Schick Lake region. See outline C, Figure 47, for location.

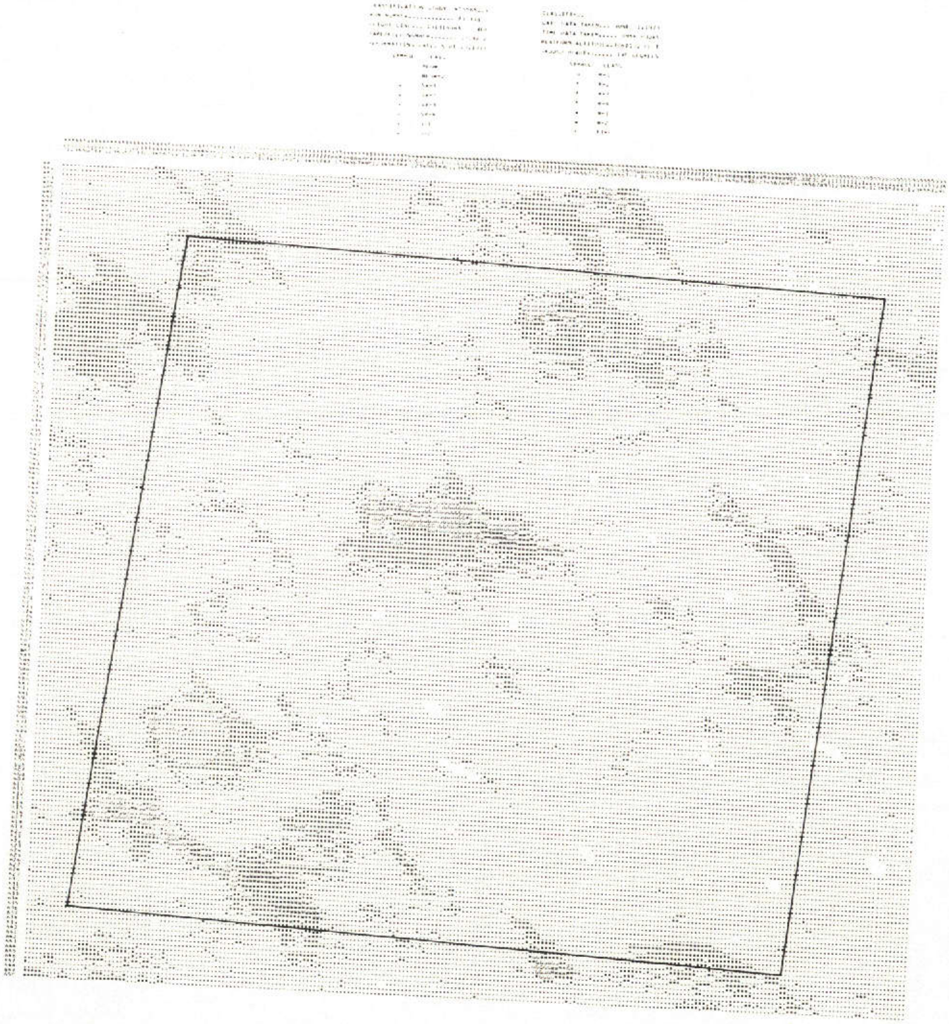

Figure 40. Computer printout spectral class map of approximately the same area as Figure 39. Blank - spectral classes A and B; . = classes C, D, E, F, G, and H; G = classes J and K; M = class L; W = classes M and N.

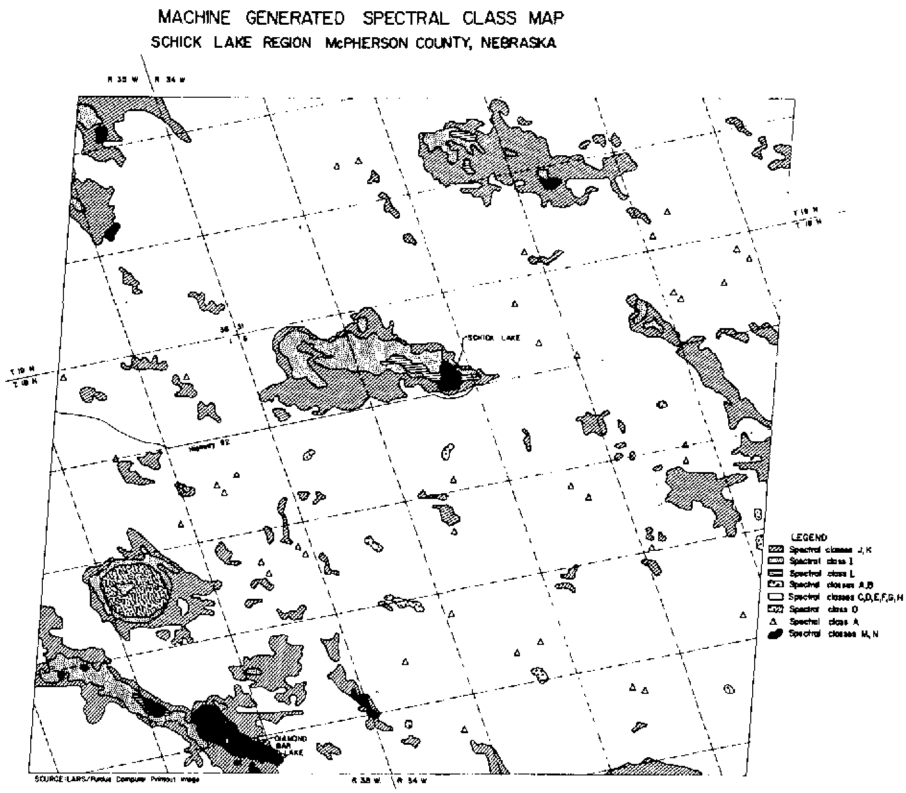

Figure 41. Overlay of spectral class map, traced directly from Figure 40.

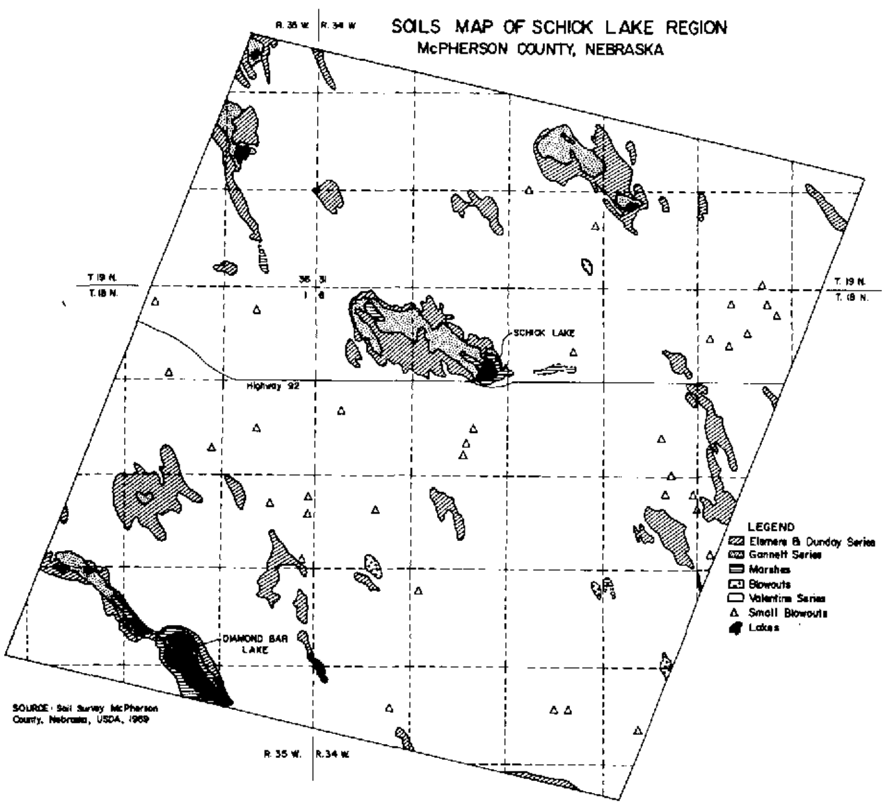

Figure 42. USDA soils map of Schick Lake area, traced directly from portions of sheets 7, 8, 13, 14, 19, and 20 of Sherfey's report.

This "ground-truth" map was taken from the McPherson County Soils Survey, sheets 7, 8, 13, 14, 19, and 20. Note the striking similarity between the two maps. Blowouts, lakes, and soil groups are in the same geographic locations; they are of the same shapes; and they are approximately the same sizes. The computer map indicates more blowouts and larger extents of Elsmere and Dunday soils. The distribution of "anomalous" Elsmere and Dunday soils on the computer map is localized along shallow topographic troughs between the northwesterly trending longitudinal dunes. These troughs are regions where conditions are favorable for formation of Elsmere and Dunday soils. Therefore, it is not unreasonable to expect these soils to exist at the locations indicated on the computer map. The authors believe that the method of mapping described in this report, with judicious interpretation, offers a capability to upgrade many surface cover type or soils maps constructed by conventional techniques. This does not imply that all surface mapping units nor all geographic areas are equally adaptable to such machine-aided analysis.

Another technique developed at LARS/Purdue allows the user of the LARSYS system to suppress display of one or many spectral classes in order to emphasize distribution of other classes. To demonstrate this capability, an area of severe blowouts northeast of the junction of Birdwood and Squaw Creeks was chosen for display. Figure 43 shows two pictures of the same area. Figure 43A is displayed with the same gray scale code as Figures 33, 38, and 39. Blowouts appear white. The larger ones can be seen, but their outlines are indistinct, and many small blowouts are impossible to distinguish. Figure 43B suppresses the contrasting gray tones of all classes except blowouts (white). River bottoms appear as black to aid in geographic orientation. On the blowout accentuated image, blowout locations and sizes are easily discernible.

Blowouts (Figures 44 and 45) are an economic detriment in the Sand Hills region. Commonly, as seen in Figure 44 with the white-faced culprits caught red-handed, cattle walking along fence lines disturb the grass cover and initiate blowout development. The tires in the foreground of Figure 45 are not the beginnings of a trash heap but, hopefully, the ending of a blowout. Field observations indicate that old tires are used commonly to line incipient blowouts in an attempt to stabilize moving sand. Timely and accurate location of constantly changing blowouts can significantly reduce the erosional loss of rangeland. Thus, maps obtained from analysis of satellite data can provide both needed timeliness and accuracy.

Two other class accentuation images are shown in Figure 46. Both photos are of the same area covering parts of western McPherson County and eastern Arthur County (see Figure 17,

A

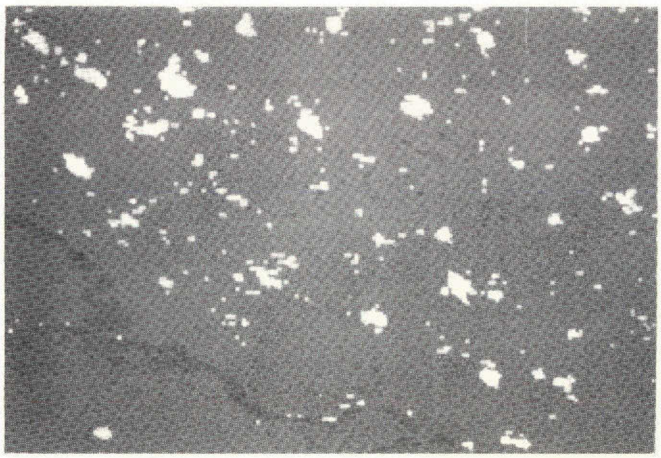

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Figure 43. Computer digital map of severe blowout area in McPherson County (outline D, Figure 47). Figure 43A displays all classes with same gray tones as Figures 33, 38, and 39. Figure 43B suppresses most classes for emphasis of blowouts (white).

Figure 44. Beginnings of blowout. Blowout development is commonly initiated along cattle trails adjacent to fence lines.

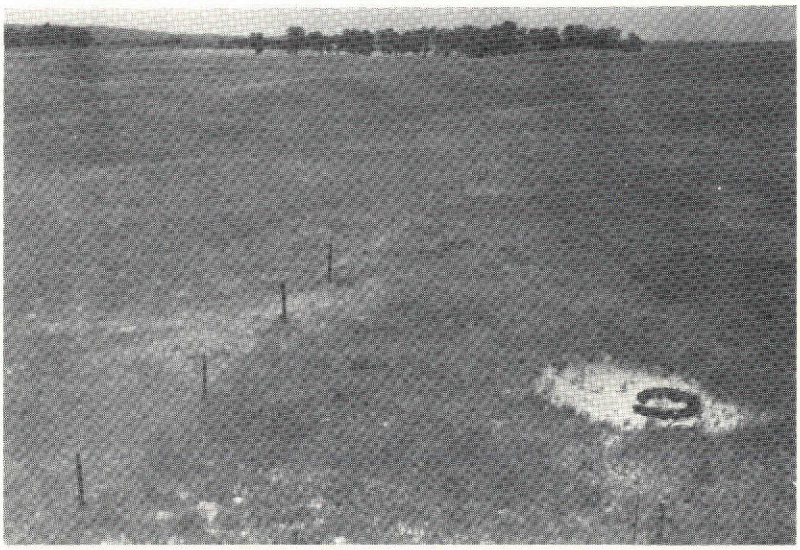

Figure 45. Small, incipient blowout with worn out tires placed along the edge to retard wind erosion.

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A

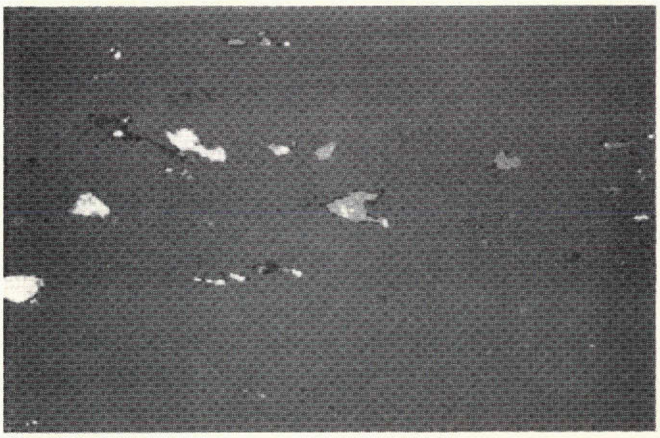

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Figure 46. Spectral class accentuation map of the lake area (outline E, Figure 47). Figure 46A, white = wetlands; black = lowlands. Figure 46B further accentuates wetland classes. White = permanent lakes; light gray = temporary lakes; black = marshes.

outline E). This area is a lake district of the Sand Hills, and is marked by many wet lowlands comprised of marshes, ponds, and productive hay areas. Figure 46A displays the depressional areas as black and white in a medium gray tone matrix. Black areas are lowlands suitable for hay cutting. These haylands surround or border on the west the marshes, lakes, and ponds, as shown in white. To further accentuate the character of these water-covered areas, Figure 46B separates for display three classes of wetlands. White represents permanent lakes. Light gray portrays areas of shallow, seasonal lakes, filled at this time of year, 1 June 1973, by late spring and early summer rains. These seasonal rains raise the water table and produce numerous ephemeral lakes and ponds. Black areas of Figure 46B are marshes, many also seasonal. These wetlands offer recreational activities such as fishing, duck hunting, and swimming, and as such are economically important in our era of leisure dominated lifestyles.

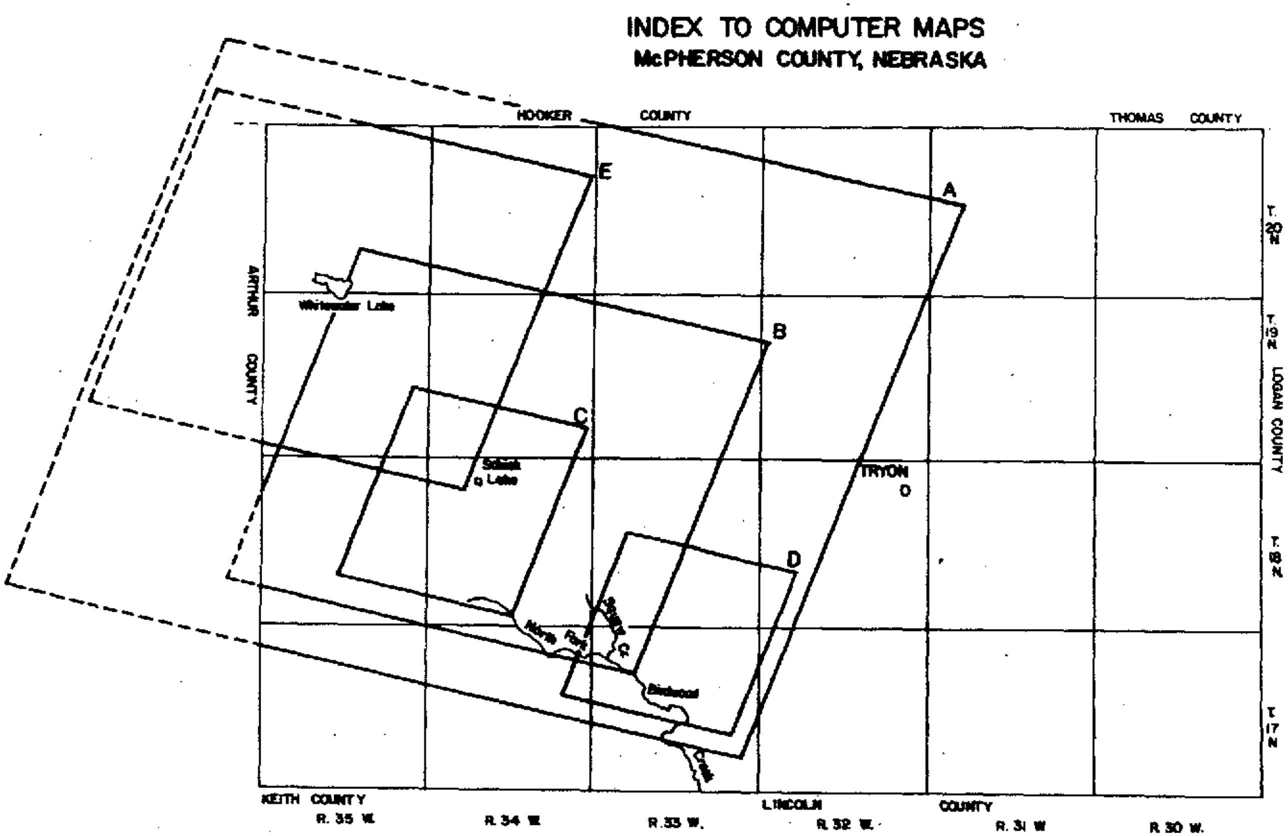

Figure 47. Location index map for all computer maps discussed in text, and referenced in Figures 33, 38, 39, 43, and 46.

F. WELLS COUNTY, NORTH DAKOTA ANALYSIS

After initial inspection of the data it was decided to attempt to make a land use map of Wells County, North Dakota. Also a comparison of soils and surficial geology to the ERTS data was planned. The first objective could best be accomplished using the LARSYS system of computer processors on digital ERTS data collected 5 September 1972 (Scene ID 1044-16595). For the comparison of ERTS data and soils and surficial geology, photo interpretation techniques were used on ERTS data collected 9 April 1973 (Scene ID 1260-17010).

Wells County, North Dakota is located in the center of the state on the border of the Missouri Coteau and the Drift Prairie. The area was completely covered by late Wisconsin glacial ice which was responsible for all the present landforms and glacial deposits. The Missouri Coteau is a dead ice moraine composed of glacial drift located in the southern third of the county. The remainder of the county is a mixture of glacial and fluvial-glacial deposits. Most of the area is ground moraine, although large areas of outwash deposits are present. Patches of end moraine can be found on the Drift Prairie while the largest accumulation of end moraines are in the northeast corner of the county. Glacial and fluvial-glacial landforms which are present in the county include dead ice, end, washboard, and ground moraines; elevated and collapsed lake deposits; kames; eskers; outwash plains; and meltwater trenches.

Most of the county is farmed, with approximately 60% of the county cultivated. Major crops in the county include spring wheat, flax, and barley. Much of the county is in pasture, primarily for raising beef cattle. The population of the county in 1960 was 9,237 with 920 people living in Fessenden, the county seat, and 2,365 people living in the town of Harvey.

Two types of data were used in this analysis: (1) geometrically corrected ERTS digital MSS data, and (2) color and color IR underflight photography. The ERTS data were collected 5 September 1972 (Scene ID 1044-16595) and 9 April 1973 (Scene ID 1260-17010). In addition to the ERTS data, color and color IR aerial photography was available from approximately the same time (14 September 1972 and 14 May 1973). This photography was used in conjunction with published soil and geologic maps as ground information.

Digital ERTS data were processed using the LARSYS software system of computer programs. Using the aerial photography as ground information, areas with similar cover types were selected as training areas. These areas were then clustered to obtain spectrally separable subclasses, and the statistics from these subclasses were then used to classify the county area. Results were obtained in both pictorial (from the PHOTO processor) and tabular (from the PRINTRESULTS processor) form.

Three classes were classified using the 5 September 1972 data: (1) cultivated, (2) pasture, and (3) water. The cultivated class had fallow and bare soil subclasses. The pasture class included pasture and some trees which are used as windbreaks.

Two problems were encountered in this analysis: (1) there was not enough ground information to properly test the classification accuracy, and (2) there was not a large enough urban area to get a usable training set. The only ground information which was available for this part of the analysis was a North-South flightline over Fessenden, the county seat. Classification results were compared with the photography and the classification seemed to be quite accurate along the flightline. Because of the small population of Wells County, 9,237 in 1960, there was not a large enough urban area to obtain valid class statistics. The area which should be classified as urban was classified as pasture. This misclassification will raise the area classified as pasture, but because of the limited area misclassified, it should not be significant.

Table 13 shows the area estimates which were made from the classification of the 5 September 1972 ERTS data. These figures show the highly agricultural nature of the county. The pasture class is slightly higher than it should be because of the inclusion of urban and forest areas in this class. Both urban and forest were so poorly represented in the county that it was impossible to obtain class statistics for them. Figure 48 shows the land use classification of Wells County using 5 September 1972 data.

Table 13. Area Estimates from Land Use Classification of ERTS Data Collected 5 September 1972.

Class	Points	%	Area Hectares	(Acres)
Cultivated	499293	60.02	182183	(499,366)
Pasture	330225	39.70	120534	(330,304)
Water	2313	.28	850	(2330)
Total	831831	99.98	303567	(832,000)

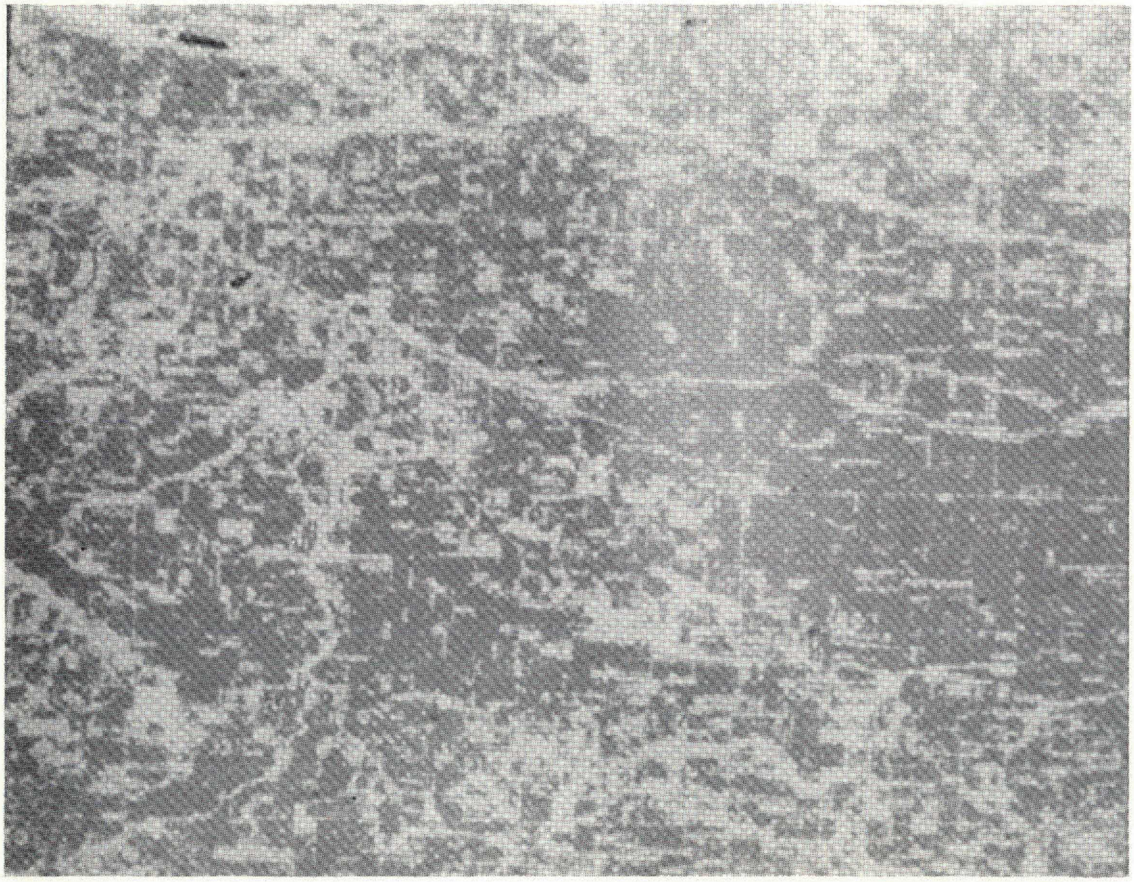

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Figure 48. Photo from the Digital Display of a Classification of Wells County, North Dakota Using Data Collected 5 September 1972.

Gray - Cultivated land   Black - Water
White - Pasture

Figure 50 is a photo of band 7 (9 April 1973) taken from the digital image display system. Most of the county is included in this photo. By comparing this photo with the geologic map (Figure 49) several of the major geomorphic areas can be outlined: (1) the dead ice moraine of the Missouri Coteau, (2) area of ground moraine, (3) glacial outwash, and (4) end moraines in the northeast portion of the county. Figure 51 is an enlargement of the northwest corner of Figure 50. In this photo it is possible to identify some of the structure (A) association with outwash plains and several meltwater channels (B) dissecting ground moraine. The soils of Wells County generally are associated with the geologic parent material, but are classified using additional criteria of organic content, slope, etc. Because these additional criteria cannot readily be interpreted from ERTS data, specific soil associations will not be described here. For more information pertaining to mapping soils from ERTS data, other sections of this report should be consulted.

It has been shown that land use maps and general surficial geology maps can be produced from ERTS data. Data collected during the summer or early fall is best suited for producing land use maps because the ground is covered with crops or pasture, indicative of its use. To effectively produce a geologic or soils map, data should be collected when there is as much bare soil as possible so that what is being interpreted is ground surface and not ground cover.

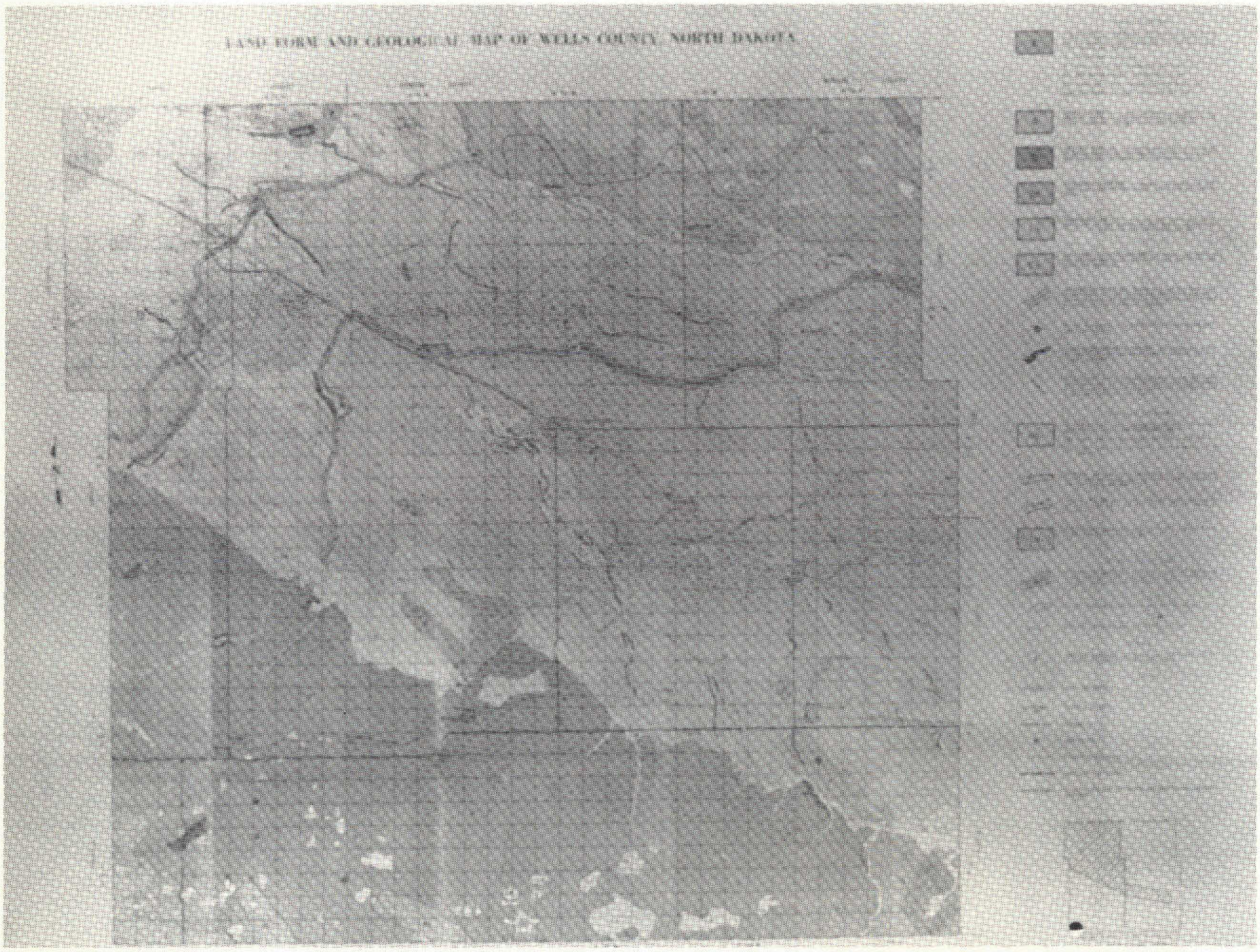

Figure 49. Surficial Geology Map of Wells County, North Dakota.

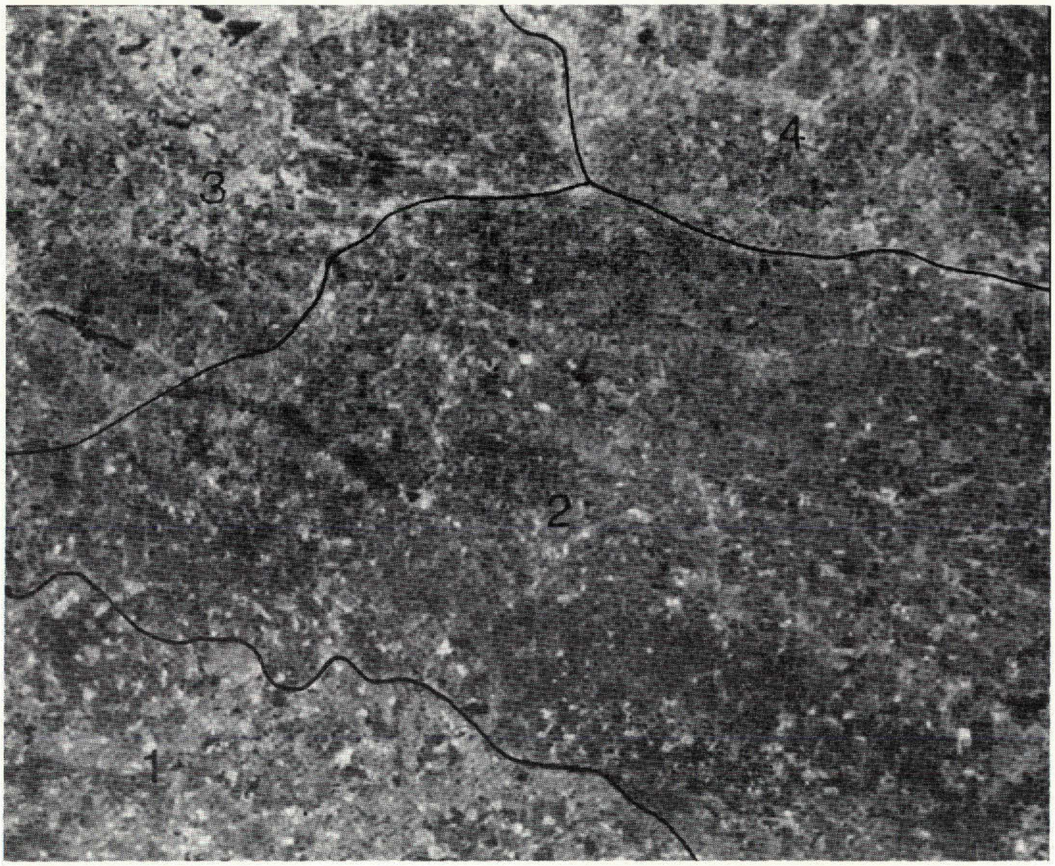

Figure 50. Photo from the Digital Display of Band 7 (0.8-1.10μm) of Wells County, North Dakota Using Data Collected 9 April 1973.

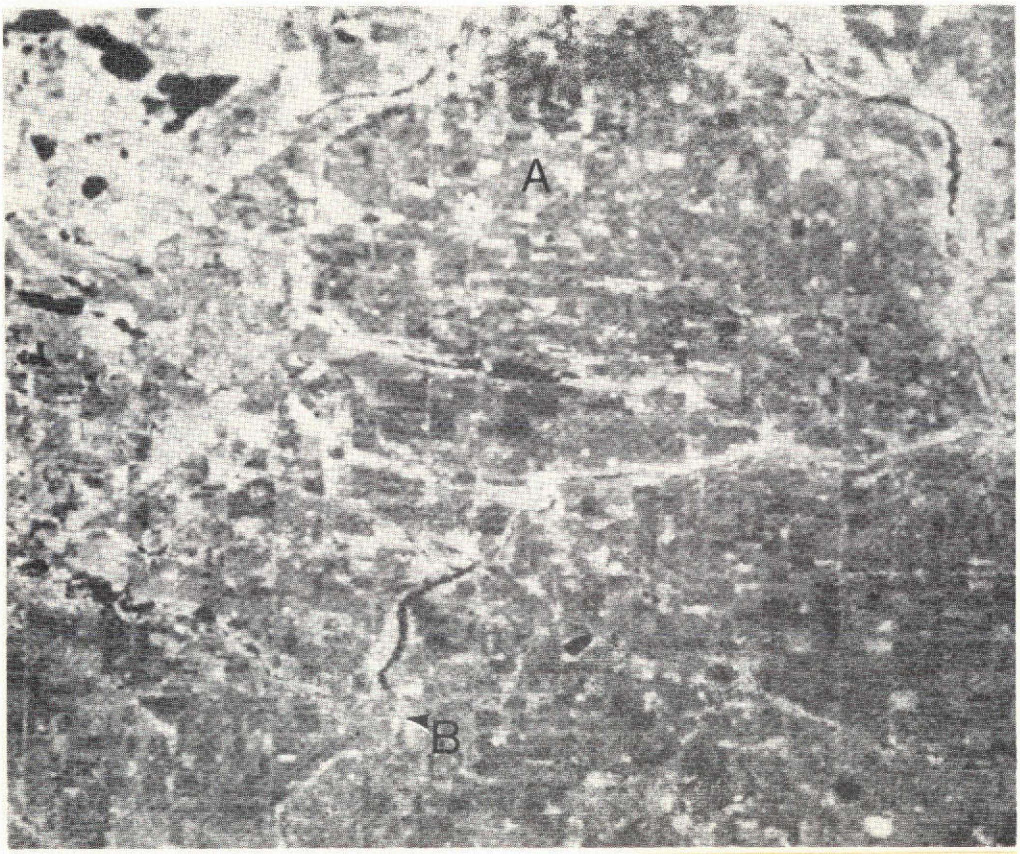

Figure 51. Photo from the Digital Display of Band 7 (0.8-1.10μm) of Wells County, North Dakota Using Data Collected 9 April 1973.

G. OTHER ANALYSIS

1. WATER RESOURCES STUDY

a. Huntington-Salamonie River Reservoir Complex Study

Soil erosion is a main contributor to degradation of a watershed. Loss of valuable natural fertility, filling of reservoirs with sediment, and actual loss of land are the end result of soil erosion. Soils under cultivation are most susceptible to erosion during periods of soil preparation for planting. Periods of a high rate of erosion also occur during establishment of cover. The repetitive cultivation of intensively farmed agricultural lands exposes these soils to the erosion processes much more. Therefore, lands under cultivation contribute a major portion of the sediment in our streams and rivers.

A preliminary investigation of selected watersheds was undertaken to develop techniques by which agricultural cover types may be delineated in a watershed. Delineation of agricultural lands under cultivation is the first step toward monitoring the erodible lands and the resulting erosion.

This study was conducted on a portion of the upper Wabash River watershed in east-central Indiana. Parts of the upper Wabash, Salamonie and Mississinewa watersheds plus their respective reservoirs were selected for this pilot study.

MSS data collected by ERTS on 17 October 1972 (Scene ID 1086-15532) was obtained and processed using the LARSYS computer system. Approximately 800,000 hectares (about one-fourth of the frame) was selected as being representative of the study area by observation of single wavelength band imagery. Ground features were identified using the digital image display processes and input as training sets into cluster and classification functions. Those features identified included agricultural lands, forests, reservoirs and urban-residential areas.

Figure 52 is a photographic representation of the spatial location within the study area of the different ground control features. Also, each data point has a unique location and can be assigned to only one class so that the total area occupied by a certain feature is readily available.

The PRINTRESULTS function was used to obtain the area included in each of the classes. From the PRINTRESULTS processor

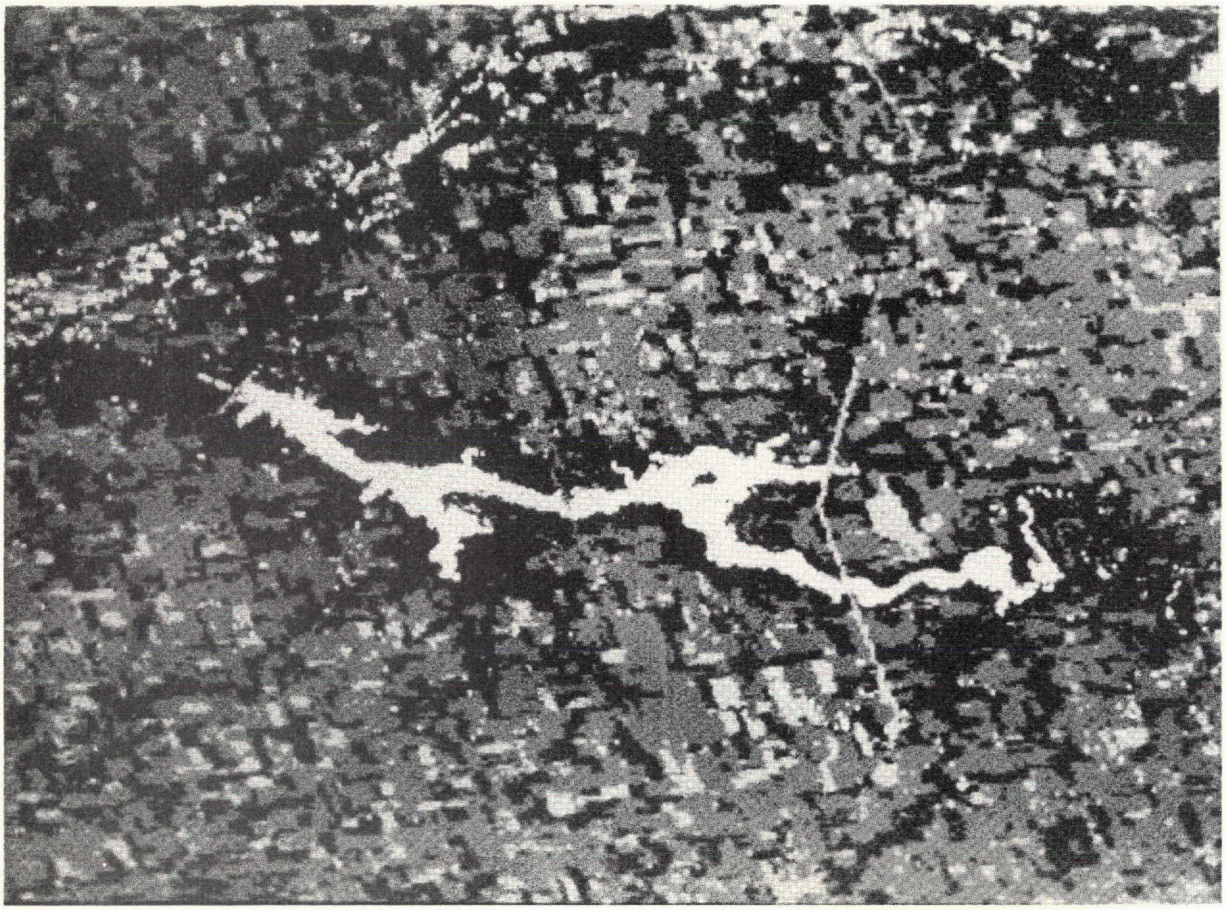

Figure 52. Classification of Salamonie River Reservoir Area Located in Northeast Indiana.

White - reservoir water Dark gray - row crops
Light gray - pasture Black - forest

an estimate of land area in agriculture can be obtained. This information will be combined with soils information to produce an estimate of erodible land under cultivation. In addition to assessing current potentially erodible soils, subsequent ERTS frames may be analyzed to determine changes in agricultural land use which will affect soil loss. This information will be important in projecting economic life of reservoirs and other flood control projects.

b. Lavon Reservoir Study

This study was conducted on the Lavon Reservoir in Collin County, Texas. Using the ERTS multispectral data of that area, analyses were made to determine the agricultural applicability of data taken at satellite altitudes to map natural and/or man-made features. This study had as its primary objectives: to determine how well the water within the reservoir could be separated spectrally; to map the drainage patterns of the area surrounding the lake; to map the heavily wooded areas versus nonwooded areas; and to determine if cotton could be separated from other green vegetation.

The study area is located in northeast Texas, approximately 50 miles north of Dallas, in Collin County. The nearest city, having a population greater than 10,000 is McKinney, the county seat, about 15 miles northwest of the reservoir.

The area of interest was displayed on an IBM Digital Image Display System. After examining the digital data in each ERTS MSS channel, training sets, representing major differences in cover types, were selected for analysis of the data, by outlining several non-uniform relatively large areas with a light pen. These coordinates were automatically punched on computer cards.

At first only areas other than water were considered. Cards defining several ground areas were submitted to a specialized computer program in order to separate spectrally fourteen classes. Representative x,y coordinate cards were obtained for each category. By adding one set of cards representing water to the existing fourteen separable classes, it was then possible to classify all points within the study area into one of these fifteen categories.

Several areas were selected from within the lake and submitted to the previously mentioned processor to separate spectrally ten classes of water. Again, representative x,y coordinate cards were obtained from the computer for each of the ten classes.

When these ten categories for water were added to the fourteen classes for land features, it was possible to classify the entire study area into 24 spectrally separable categories.

Mean reflectance values had been previously obtained for each of the 24 classes, modified for use at this Laboratory by Dr. S. J. Kristof, ratio values were obtained by dividing the sum of the values in the visible spectrum (0.50-0.70μm) by the sum of the values in the infrared region (0.70-1.10μm). This method is based on the theory that lush green vegetation will reflect a large (over 50%) percent of its total reflectance in the infrared region, while soils, roads, rocks and other geological and man-made features will give a higher percent reflectance value in the visible region. Therefore, ratio values lower than 1.00 could be classified as green vegetation, whereas soils would have values greater than 1.00. Water, due to its great absorption of energy in the infrared portion of the spectrum would have values greater than 2.00.

Based on the numerical similarities between these ratio values, some classes were combined. It was in this manner that the original 24 classes were reduced to 18, 10 of which represented different ground features and 8 of which represented the spectrally different classes of water. These classes were then reclassified and a computer-generated map of 18 spectral classes was produced.

During the month of August 1972, ground observation data were obtained for a number of features within this area. By comparing these data to the computer generated map, it was found that the wooded areas had been clearly and correctly outlined. Ground observation data were not sufficient to assess quantitatively the accuracy of identifying cotton. However, the available ground observation indicates that cotton was separated from other vegetation with a rather high degree of accuracy. By referring to the vegetation commonly associated with drainage, the drainageways leading to the reservoir were clearly distinguishable. By using the same reasoning, the soil association patterns were made visible.

The eight spectral categories of water probably differed in depth, turbidity, sediment load, and algal growth. Ground observations indicate that the depth of water was 3.5 m in the northern part of the reservoir. In the southwest part of the lake a distinct spectral class proved to be shallow water interspersed with a high population of dead tree stumps.

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Figure 53. The Lavon Reservoir area in Collin County, Texas obtained from 25 July 1972 ERTS imagery. The area is displayed as 18 spectrally separable classes: 10 of which are water.

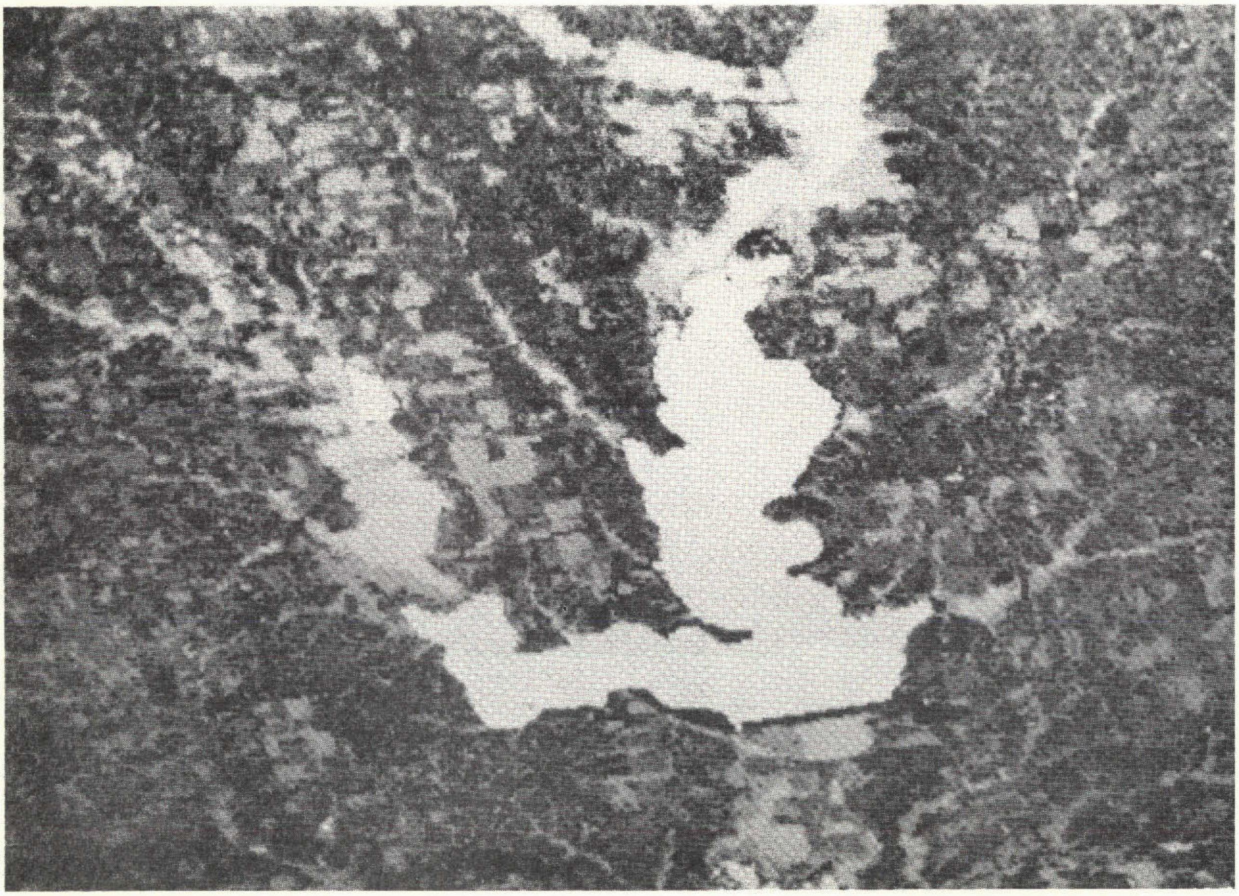

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Figure 54. The Lavon Reservoir area in Collin County, Texas obtained from 25 July 1972 ERTS imagery. The area is depicted by 11 spectrally separable classes.

2. MOLLISOL STUDY

Of all the soils in the Central United States, the soils of the order Mollisol are probably the most productive. The name Mollisol itself implies that the soil is pleasant to work with. These soils are prominent, and may be generally characterized as soils with a deep, dark surface layer (A horizon) which is rich in organic matter and bases. If agricultural production in the United States is to remain sufficient for our needs in future years, proper management of these more productive soils is imperative.

Contrary to popular belief, there are many counties in the United States which never have had or have no current, usable soil maps. Good maps take a lot of time to produce and require a great deal of money. Many counties cannot afford to pay their portion to have a comprehensive soil survey produced, yet adequate soil maps are needed today. Perhaps maps produced from multispectral ERTS imagery may help the soil mapping move faster on the ground.

The goal of this particular investigation was to examine the spectral variability of one selected soil order, Mollisols, over a large spatial distribution. In order to extrapolate observed phenomena from one area of interest to another, it is necessary to know how much relatively fixed features are varying; in this specific case, spectral variation of Mollisols observed over large geographic distances on different frames of ERTS imagery.

The literature seems to indicate that for aircraft one cannot extrapolate observations about soil types over long distances. Kristof and Zachary (1971) found that soil types varied quite a lot from one end of a 35 kilometer flightline to the other. Mathews (1973) found that as he moved farther away from his ground control, the reliability of identifying soils using multispectral aircraft imagery decreased. No literature was available concerning satellite imagery when this project was initiated.

The areas selected for this investigation were five: Boone County, Indiana; Wells County, North Dakota; Humboldt County, Iowa; Greeley County, Kansas; and Hale County, Texas. All of these counties contain large areas of soils in the order Mollisol. They all also have a recent comprehensive soil survey. The soil survey was used to locate fields in the ERTS imagery whose soils were Mollisols. Four fields were selected from each county to act as replications. The data points were averaged from each field for each of the four wavelength bands. One observation was then equal to the mean spectral response of one specific field in one specific county in one specific wavelength band. The wavelength bands of the ERTS multispectral scanner are:

Band 4	0.50-0.60 micrometers	green
Band 5	0.60-0.70 micrometers	red
Band 6	0.70-0.80 micrometers	infrared
Band 7	0.80-1.10 micrometers	infrared

The image description of the five frames used is as follows:

County	State	Date Obtained	ERTS Scene ID
Boone	Indiana	June 9, 1973	1321-15593
Wells	North Dakota	May 15, 1973	1296-17005
Humboldt	Iowa	May 10, 1973	1291-16332
Greeley	Kansas	June 19, 1973	1331-16571
Hale	Texas	June 18, 1973	1330-16524

A plot of the mean spectral response for each area vs. wavelength is shown in Figure 55. It is apparent that there are some distinct differences between the areas.

The Analysis of Variance model for this study was a nested split-plot design.

$$Y_{ijk} = \mu + A_i + R_{(i)j} + \delta_{(ij)} + W_k + AW_{ik} + RW_{(i)jk} + \varepsilon_{(ijk)}$$

where:

Y_{ijk} = response of the kth wavelength band from the jth replication within the ith area;

μ = overall mean;

A_i = variation due to the ith area;

$R_{(i)j}$ = variation due to the jth replication nested within the ith area;

$\delta_{(ij)}$ = restriction error due to nesting of replications within areas;

W_k = variation due to the kth wavelength band;

AW_{ik} = variation due to the interaction of the ith area with the kth wavelength band;

$RW_{(i)jk}$ = variation due to the interaction of the jth replication nested within the ith area with the kth wavelength band;

$\varepsilon_{(ijk)}$ = error.

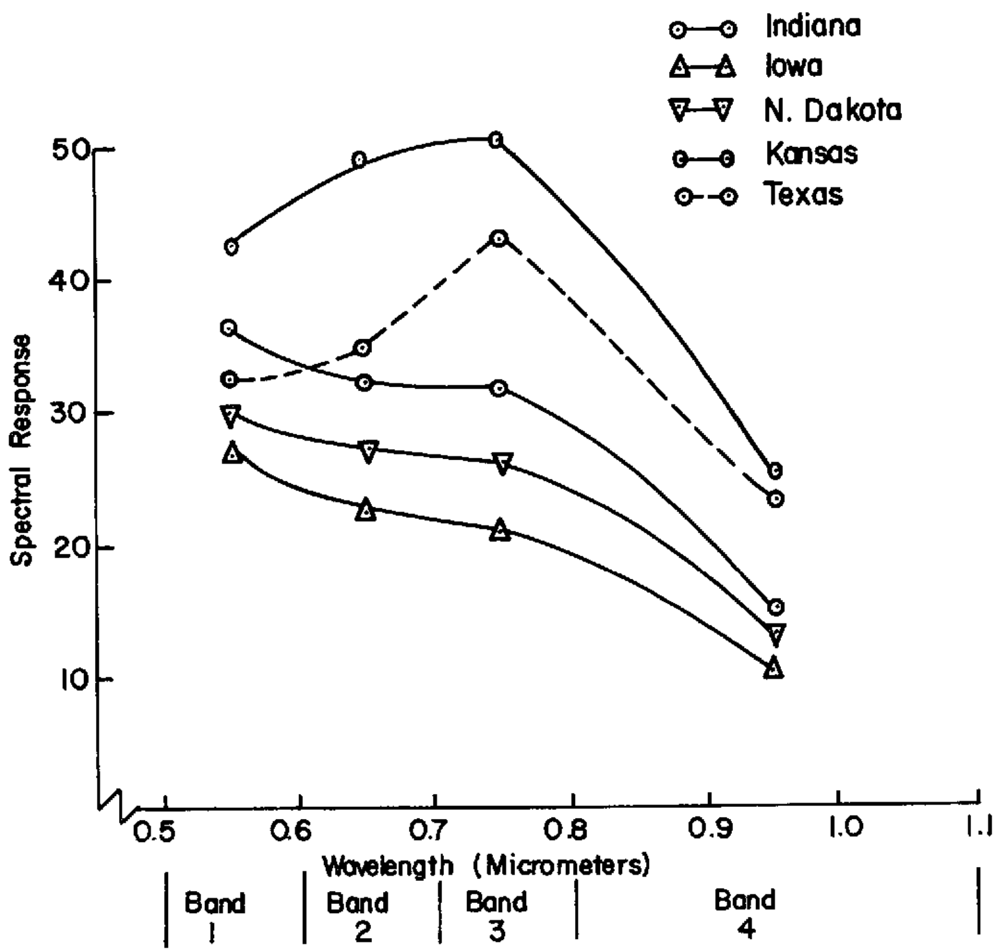


Figure 55. Plot of mean spectral response vs. wavelenth for each test site.

Table 14. The Results of Analysis of Variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Sign. of F-test	Expected Mean Squares
A_i	4	4463.12	1115.78	*	$\sigma^2 + 4\sigma^2_\delta + 4\sigma^2_R + 16\sigma^2_A$
$R_{(i)j}$	15	303.26	20.22	No valid test	$\sigma^2 + 4\sigma^2_\delta + 4\sigma^2_R$
$\delta_{(ij)}$	0				$\sigma^2 + 4\sigma^2_\delta$
W_k	3	4102.05	1364.02	*	$\sigma^2 + 20\sigma^2_W$
AW_{ik}	12	712.35	59.36	*	$\sigma^2 + 4\sigma^2_{AW}$
$RW_{(i)jk}$	45	124.08	2.75		σ^2
Total	79	9704.86			

* indicates a significant differences as found by an F-test at $\alpha = 0.05$

The results of analysis of variance indicate that the variations due to (1) areas, (2) wavelength bands and (3) the interaction of areas with wavelength bands are all significant at $\alpha = 0.05$. The variation due to wavelength bands was expected as the phenomena of soils reflecting quite differently with wavelength is well documented. However, if we are to extrapolate our results between areas or between frames of ERTS imagery, the variation due to areas and the variation due to the interaction of the areas with wavelength bands both should be small. In this case, both are significant variations.

It was hypothesized that perhaps one or two of the areas examined were contributing most of the variation. To examine this possibility, a test for determining if the means of the areas or the interaction means were significantly different was performed (Newman, 1939 and Kuels, 1952). Fifty possible cases of variation existed for the area means and interaction means. All fifty cases were examined and only two cases were not significantly different. Of the interaction means, the response in wavelength band 4 was not significantly different between Hale and Greeley counties and between Wells and Boone counties. In all of the cases, the area means were significantly different.

One conclusion which must be drawn from this investigation is that it is not safe to extrapolate results, for Mollisols, over large distances or from one frame of ERTS imagery to another without some ground control for each area. It must be understood that the soils themselves vary due to geologic location. Organic matter content, surface soil color, and surface moisture content are the major contributors to geographic variation. Realistically though, these are variations which will exist over a large areal distance, and it appears that the multispectral ERTS imagery is sensitive to variations of this magnitude. Therefore, extrapolation without sufficient ground control appears risky at this time.

Further investigation may show that the differences between Mollisols are not significant if surface soil moisture and organic matter content are included in the prediction model. Adequate ground control within the area covered by a frame of ERTS imagery would obtain this information and would raise our confidence in extrapolating results over large areal distances.

3. KANSAS CITY LAND USE STUDY

a. Introduction

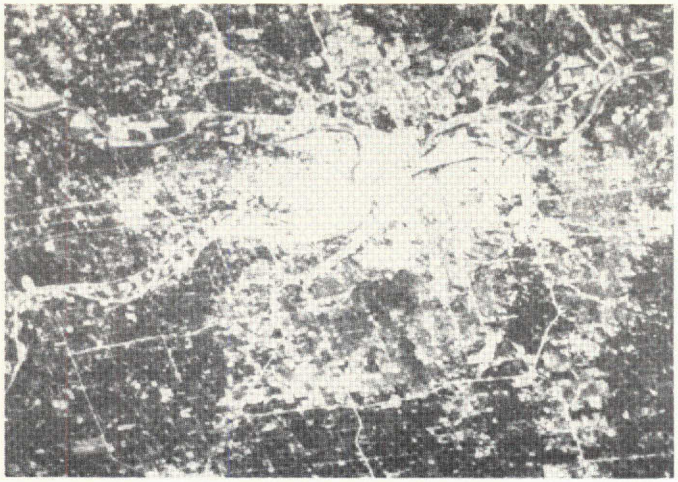
The acquisition and monitoring of land use data in large metropolitan areas is an essential task in urban and regional planning. Planners must have timely and accurate data to make good decisions regarding land use. One data source is NASA's Earth Resources Technology Satellite, launched in July 1972. The satellite can collect data over any given city every eighteen days, weather permitting.

On 13 August 1972 a frame of data collected by the satellite was cloudless over a large area in Kansas and Missouri (Scene ID 1021-16333). The Kansas City, Missouri-Kansas subframe (Figure 56) was chosen for land use analysis. The subframe includes all or part of seven counties: Clay, Johnson, and Cass Counties, Missouri; and Platte, Wyandotte, Johnson, and Leavenworth Counties, Kansas. Four bands of digitized multispectral sensor data were used in the study.

b. Procedure

The four bands of data (two of which are shown as Figures A and B) were initially viewed on a digital imaging display. At that time, three functions were performed. First the areal extent of the study area was determined and a number of dominant areal features such as rivers, airports, highways, parks, and reservoirs were identified and their line/column coordinates recorded, to aid in interpretation of line printer maps. Next, several areas were chosen for the histogramming processor for future, more controlled viewing on the digital display. Finally, several small areas were chosen for a clustering processor, taking care to obtain a representative sampling of the spectral variability in areas.

Fourteen spectral classes were requested of the clustering program. The statistics from these cluster classes were used to classify all of the data points in the study area, and the results were displayed by a line printer using different alpha-numeric symbols for each class. The resulting cluster map was used in conjunction with ground observations as a base map on which small, rectangular samples of each desired spectral class could be located. Statistics from these classes were used to classify the study area again. Eight classes were used--older housing, new housing, wooded residential, commerce/industry, river water, reservoir water, agricultural areas (bright infrared reflectance), and agricultural areas (dark infrared reflectance). Gray levels used in photographing the results from the digital display (Figure 56-C) are as follows:



A

B

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C

Figure 56. Photos of Kansas City area from digital display. Image in A from the visible portion of the spectrum (Band 5, 0.6-0.7μm); B is from the reflective infrared (Band 7, 0.8-1.1μm). Image in C is the land use classification using all four bands (see text for explanation of gray levels).

Commerce/industry	- medium gray
Older housing	- black
Newer housing	- white
Wooded residential	- light gray
Agricultural areas	- dark gray
Reservoir water	- black
River water	- very dark gray

Two of the classes--older housing and reservoir water--have been displayed as black, but their areal distribution should not be confusing. There exist approximately eight small reservoirs and ponds in the classification image, all of which are located peripherally to the urbanized area. Older housing is confined to the right-center of the image, in the middle of the urbanized area.

Care must be taken in the viewing/analysis of the three Kansas City images, because the vertical and horizontal scales are different. The disparity is a result of the digital display unit; the true ratio of length to width of a data point is 4:3, while the digital display shows the data in the ratio of 1:1. The east-west scale of the imagery is approximately 1:533,000, while the north-south scale is approximately 1:663,000.

c. Results

No quantitative assessment of the accuracy of the Kansas City classification will be reported at this time, because the ground observation data either has not been fully acquired or has not been fully correlated with the ERTS data. However, evaluation of limited ground observation data allows qualitative remarks concerning the accuracy of classification to be made. Valuable assistance in the acquisition of ground truth was given by representatives of the Cooperative Extension Service (U.S. Deparment of Agriculture, University of Missouri Extension Division).

The spectral class commerce/industry is found primarily in the center of the urbanized area, near the confluence of the Missouri and Kansas Rivers, and primarily in four municipalities: Kansas City, Kansas; Kansas City, Missouri; North Kansas City, Missouri; and Independence, Missouri. Rooftops and concrete are the two primary constituents of this spectral class.

Areas of older housing are found in the same four municipalities as commerce/industry, surrounding the latter class. Population density is relatively high in these areas, owing to the close spacing of structures and the multi-family dwellings. Mature vegetation (trees) and rooftops are the dominant land cover types of this class.

Wooded residential areas are older, upper income areas. A single, large area is found approximately four miles southwest of the Central Business District of Kansas City, Missouri. The area includes the municipalities of Fairway, Mission Hills, Prairie Village, all in Kansas, along with the residential area in Kansas City, Missouri known as Country Club. Green vegetation, as well as rooftops, are the dominant areal features of this class.

Areas of newer housing surround the three classes described above. Single-family residences built on moderately-sized lots are the characteristic land use. Lawns (grass) and roads (concrete) are probably the two main constituents contributing to the spectral nature of this class. Not unusually, therefore, interstate highways and other main roads were classified as newer housing.

The distribution of water was limited to reservoirs, lakes, ponds, and rivers. The two types of water--reservoir water and river water--were easily separated because of the variation in the visible bands. Reasons for the water differences are most likely related to silt load and pollution. A problem arose in the classification of the Kansas River near its confluence with the Missouri. Data points were frequently confused with commerce/industry, owing to the ten bridges which span the river in that small distance.

Agricultural areas, located around the perimeter of the classification image, presented the greatest difficulty in classification. Many data points in those areas were misclassified as newer housing. Green vegetation, of course, is the principal component of the agricultural classes. Usually, urban earth surface features such as parks, golf course, and cemeteries were also classified into this spectral category.

d. Conclusions

It is believed that the results of this investigation warrant serious consideration by urban-regional planners of the possibilities of computer processing of ERTS MSS data. Urban land use was mapped with good accuracy and the problems encountered were minimal, i.e., can be solved by further research.

4. TEXAS-NEW MEXICO PHOTO STUDY

A survey was made to assess the utility of remote sensing data in the monitoring and mapping of arid and semiarid land resources and environments. Major features of interest which can be identified easily on ERTS imagery include: surface water, agricultural areas, urban and built-up areas, and geologic features.

Several methods of analysis are available to organizations, depending on their resources: (1) photo interpretation of black and white photography, (2) photo interpretation of color-enhanced photography, and (3) computer analysis of MSS data. Some useful analysis can be done on black and white enlargements using conventional photointerpretation techniques. In this type of analysis general soil, geologic and some land use patterns may be distinguished. In areas of high relief, limited stereo coverage may be obtained from the sidelap of the ERTS scenes. Useful information may also be obtained by using photointerpretation on color enhanced photography using three MSS channels (4, 5 and 7). Computer analysis of multispectral data is discussed more completely elsewhere in this report and will not be described here.

Because of the reproduction of only black and white illustrations in this report, interpretation of color composites will not be discussed per se. It should be kept in mind though, that the elements of color will, in some cases, increase the accuracy and completeness of the photointerpretation.

Three frames of ERTS data were used in this analysis: 2 December 1972 (Scene ID 1132-16541), 3 December 1972 (Scene ID 1133-17000), and 4 December 1972 (Scene ID 1134-17052). Black and white enlargements were made from the 70mm negatives received from NASA and were used in this analysis.

By using the side-lap which is present on two frames covering a similar area on successive days, enough parallax was present to obtain stereo vision. In areas of much relief, such as Marathon Basin in southwestern Texas, this stereo vision was readily apparent. Figure 57 is a stereo pair made from ERTS MSS band 5 collected on 2 and 3 December 1972. Anticlines and synclines (A) are present in the Marathon Basin south of Marathon, Texas (B). In addition several volcanoes (C) can be seen on the southwest side of the fault (D).

Figure 58 is an enlargement of the Bofecillos Mountain area of southwestern Texas (Band 7, Scene ID 1133-17000). The Bofecillos Mountains (A) are composed of volcanic material

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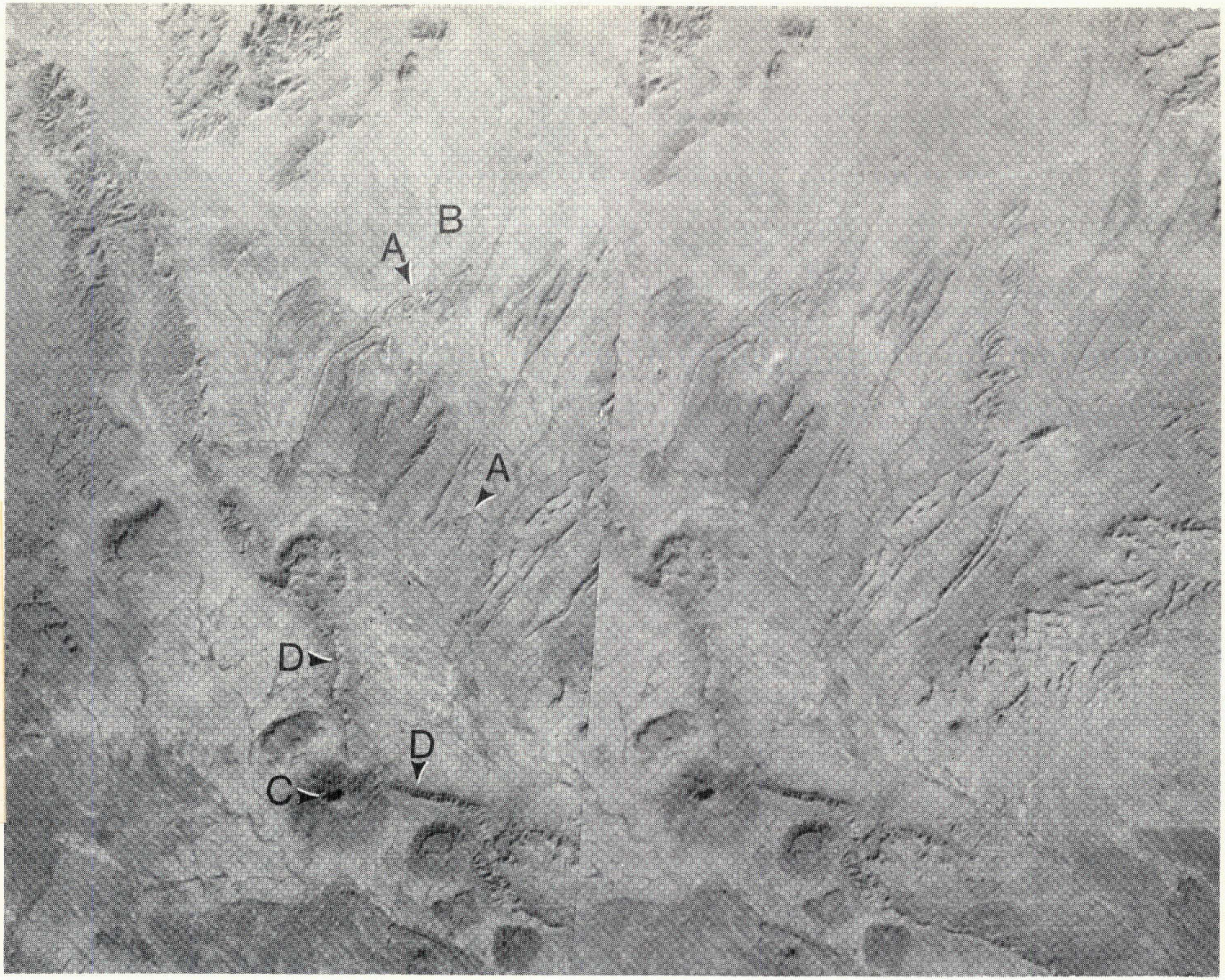

Figure 57. Stereo Pair of ERTS Photos (Band 5) from Data Taken 2 and 3 December 1972, of the Marathon Basin Area in Southwestern Texas.

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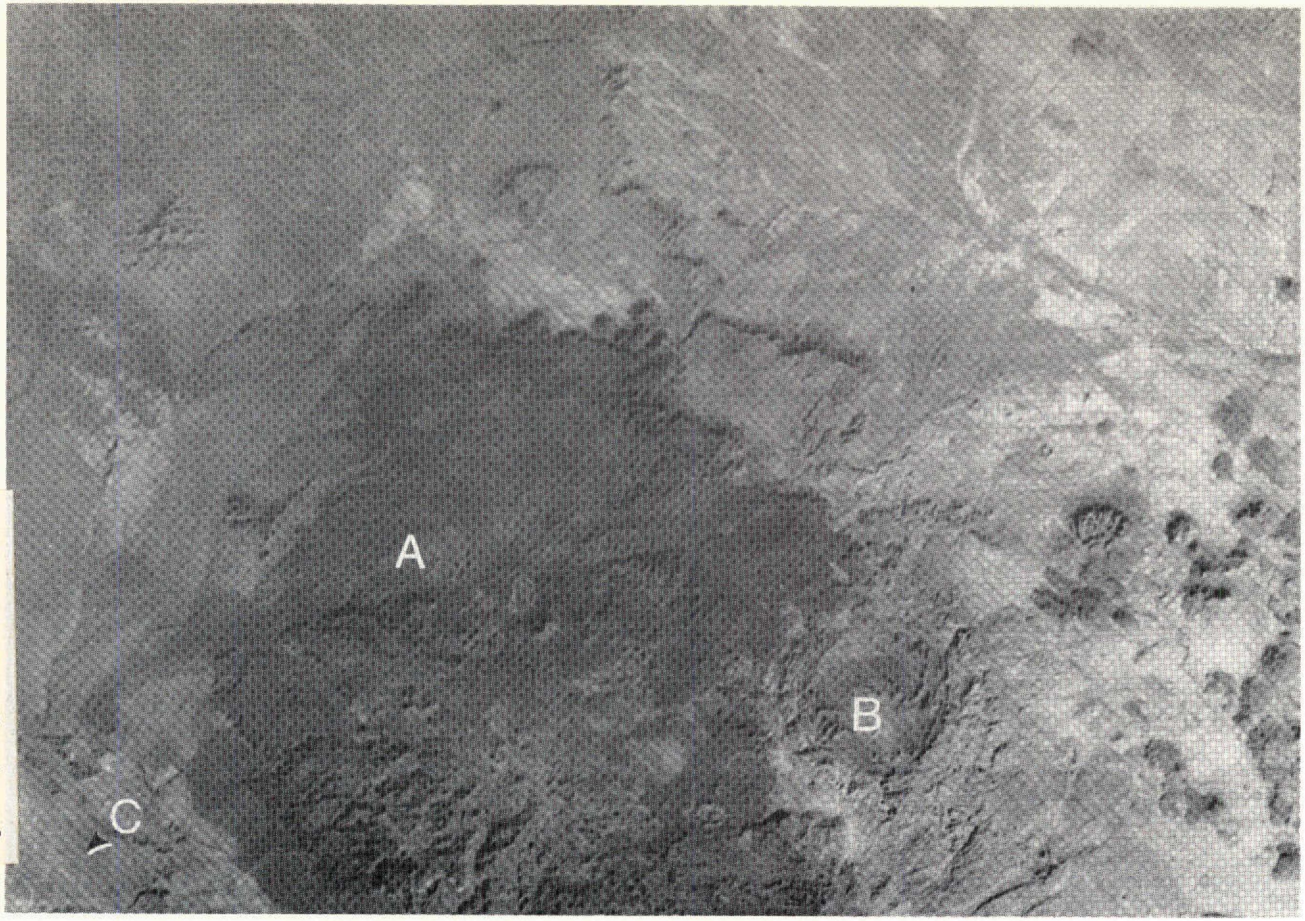

Figure 58. ERTS Photos (Band 7) Taken 3 December 1972 Near Persidio, Texas.

that has a darker tone than the surrounding sediments and sedimentary rocks. The Solitario (B) is a large dome east of the Bofecillos Mountains and is composed of lighter colored sedimentary rocks. The Rio Grande River (C) is in the southwestern portion of the scene.

From data taken 4 December 1972 on the Texas-New Mexico state line (Figure 59), obvious differences in ERTS bands can be seen. Band 5 (Figure 59a) shows very well the agricultural area (A) near the town of Salt Flat, Texas. The effect of a highway (B) on the surrounding rangeland can also be seen in this figure; to the north of the highway there is apparent wind movement of sediments while to the south of the road the rangeland is apparently unaffected. Band 7 (Figure 59b) shows the water (C) to the east of the agricultural area. Geologic features such as volcanoes (D) and the Guadalupe Mountains (E) can be seen in all bands but they appear with more detail in the band 7 image. El Capitan (F), is in the southern part of the Guadalupe Mountains.

From this analysis, it can be seen that ERTS images can be used to identify gross geologic and land use features. The main difference between aircraft photography and ERTS images is scale. Features that are large and hard to distinguish on aircraft photography may appear relatively small on ERTS data. Also the interpreter should keep in mind that features that can be routinely identified on aircraft data may be too small to identify on ERTS images.

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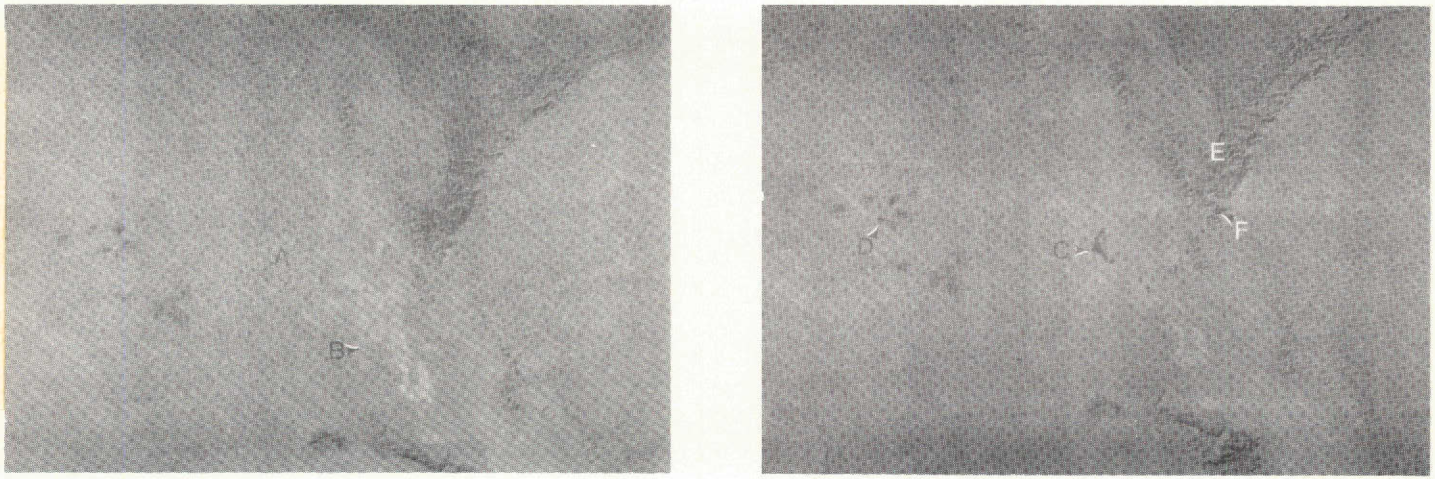


A B

Figure 59. ERTS Photos (A-Band 5, B-Band 7) Taken of the Guadalup Mountains in Southwestern Texas and Southern New Mexico.

5. COLLIN COUNTY, TEXAS STUDY

The following paper will be presented at the Tenth International Congress of Soil Science, Moscow, USSR, 12-30 August 1974, under the title, "Mapping of Soils and Geologic Features with Data from Satellite-Borne Multispectral Scanners" by M. F. Baumgardner, S. J. Kristof, and W. N. Melhorn.

a. Introduction

Today, little is known about the geologic, soils, and vegetation resources of vast areas on the surface of the earth. If these areas are to be developed, managed, and conserved for the benefit and enjoyment of man, there is need to obtain as quickly as possible an inventory of the resources of these areas.

Within the past decade, significant advances have been made in the development of airborne and space-borne sensor systems which make it possible to obtain vast quantities of earth resources data over large geographical areas within a very short time. Such data acquisition systems, coupled with computer-implemented analysis programs, provide a new, rapid reconnaissance capability for inventorying and managing earth resources.

The objective of this paper is to present the preliminary analysis results and interpretations of multispectral scanner data obtained on the first data-acquisition pass over the Central United States of the Earth Resources Technology Satellite (ERTS-1) launched by the National Aeronautics and Space Administration on 23 July 1972.

The area chosen for this study is Collin County, Texas.

b. Physical Setting

Collin County, an area of 2270 km^2, is near the northern boundary of the Gulf Coastal Plain of Texas. It is in the second tier of counties south of Red River, the boundary of the Coastal Plain physiographic province. The county may be classified as dissected, Coastal Plain upland. Drainage is southward into the Trinity River system. Elevations range from a maximum of about 250 m above sea level on the Austin scarp in the western part of the county to a low of about 150 m at Lavon Reservoir. The average elevation is about 225 m.

Geology

The geology is relatively simple. The county is underlain by an eastward and southeastward-dipping series of Upper

Cretaceous marine sedimentary rocks, overlain locally by Pleistocene fluviatile terrace deposits or recent floodplain alluvium. Change in strike of beds from north to east across the county may be in response to deposition of Cretaceous units over now buried, plunging folds of the Ouachita or Arbuckle mountain systems.

Description of the soil-forming rock units follows (Table and geologic map of Collin County, Figure 60).

Soils

Six soil associations have been identified and mapped in Collin County (Figure 61). Soils of the Houston Black-Austin association occur primarily on rocks of the Austin group. These deep, clayey soils are found on gently sloping to sloping uplands over orgillaceous marl and chalk. The Houston Black-Houston soils are associated with the Ozan and Marlbrook formations. These deep, clayey soils occur on gently sloping to sloping uplands over calcareous clays and minor limestone units. Soils formed on the Pleistocene fluviatile terrace deposits belong to the Houston Black-Burleson association. These deep, clayey soils occur on nearly level to gently sloping stream terraces.

The deep clayey and loamy soils of the nearly level floodplains belong to the Trinity-Frio association and are developed on recent alluvium. The eroded, deep, clayey soils of the Ferris-Houston association occur on sloping to strongly sloping uplands. These soils were developed on Pecan Gap Chalk and Wolfe City Formation, consisting of fine grained, calcareous sand, silt, and chalky limestone. The Wilson-Burleson soils are associated with the Eagle Ford Formation. These deep, loamy and clayey soils occur on nearly level to gently sloping uplands and are underlain by gypsum-bearing shale.

c. Procedures

Some of the first ERTS-1 multispectral data were obtained by the satellite sensor system on 25 July 1972, over a swath 185 kilometers in width along a path between Duluth, Minnesota and Corpus Christi, Texas. Within this swath an area of approximately 34,000 km^2 (185 km x 185 km) centering around the Lake Texoma region between the states of Texas and Oklahoma was chosen for analysis by the Laboratory for Applications of Remote Sensing (LARS) at Purdue University.

Digital data from the ERTS 4-channel multispectral scanner were analyzed by computer-implemented pattern recognition techniques developed at LARS. Of the four spectral channels or wavelengths,

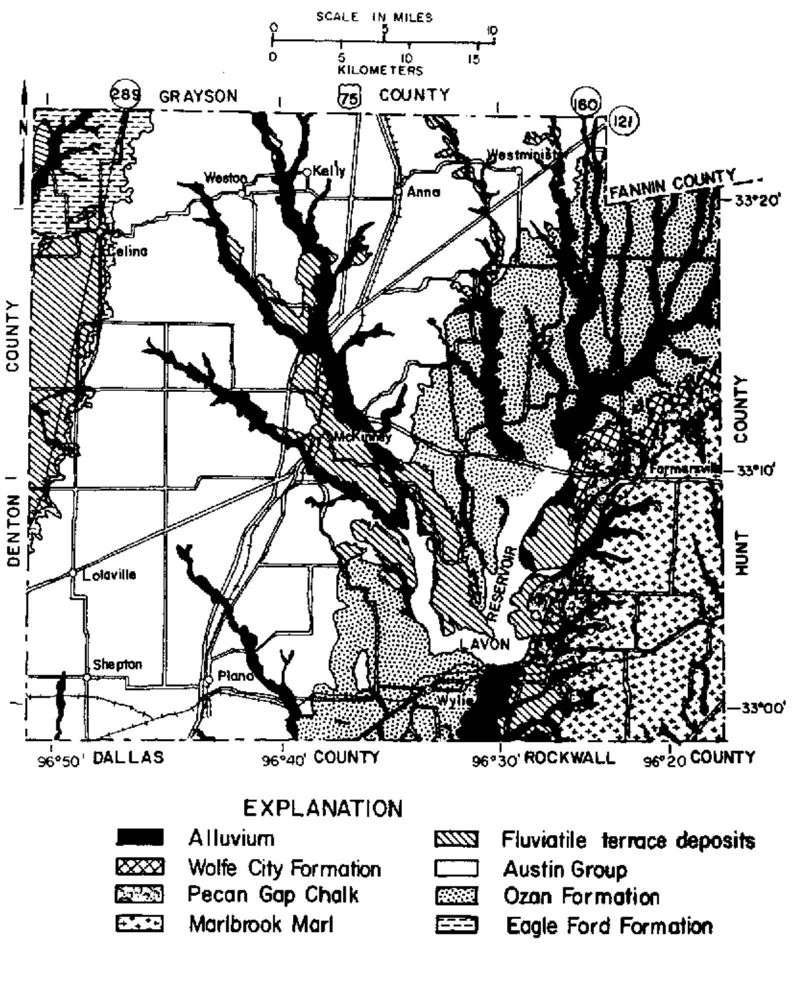


Figure 60. Generalized geologic map of Collin County, Texas, U.S.A.

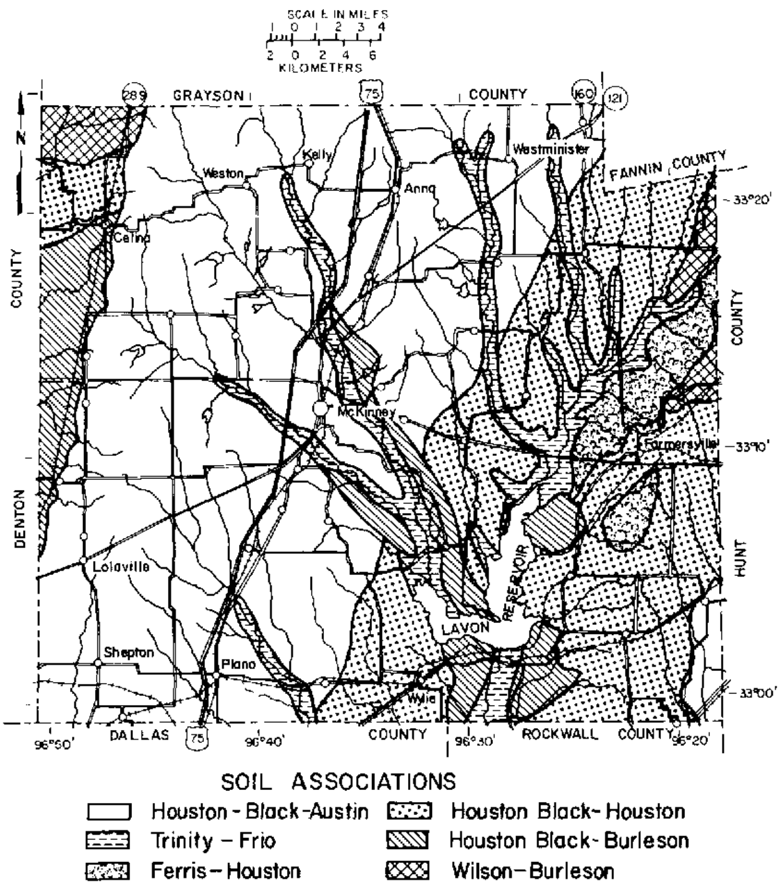


Figure 61. Generalized soil association map of Collin County, Texas, U.S.A.

Table 15. Geologic Column of Collin County, Texas.

Geologic Age	Thickness (m)	Description
Recene (Qal)	3±	Stream Alluvium
Pleistocene (Qt)	10±	Terrace deposits, dominantly gravel, sand, and silt; some clay or silty clay.
Upper Cretaceous (Santonian-Coniacian-Turonian)		
Marlbrook Marl (Kmb)	100	Calcareous, silty, glauconitic clay; in southern Collin County contains scarp-forming light gray limestone.
Pecan Gap Chalk (Kpg)	15	Alternating units of olive-gray, sandy lime and hard, granular, dark blue-gray limestone. Glauconite abundant. Sandy chalk and marl toward base.
Wolfe City Formation (Kwc)	25	Calcareous, fine grained sand and silt, with concretions; calcareous, dark gray mudstone at base.
Ozan Formation (Ko)	140	Dark gray calcareous clay; variable amounts of silt and glauconite.
Austin Group (Kau)	140-150	Regionally divided into 7 units, undifferentiated in Collin County. Dominant units are Gober Chalk (kg), and argillaceous, blue-gray, massive chalk (130 m thick); and Ector Chalk (Kec), 10 m thick, brittle, light gray, argillaceous chalk.
Eagle Ford Formation (Kef)	100-130	Blue-gray to black, bypsiferous shale. Local sand units in outcrop give rise to sand dune topography.

The contact of the Eagle Ford with the Austin group is commonly marked by a prominent, west facing topographic scarp, 40 m high locally, developed on chalk with the scarp overlooking rolling prairie or plains on Eagle Ford shales lying to the west.

two are in the visible region and two are in the reflective infrared region of the spectrum (Table 16).

Table 16. Electromagnetic Spectral Ranges Measured by the 4-Channel Scanner of ERTS-1.

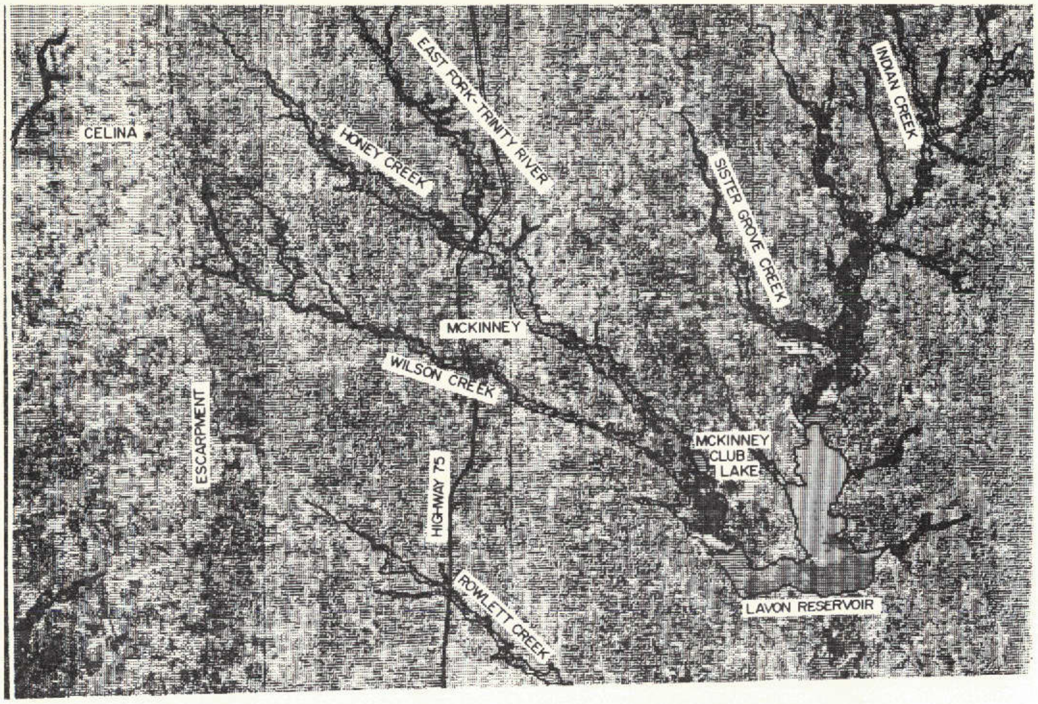
ERTS-1 MSS Band	Spectral Range	Description
4	0.5 - 0.6 μm	green
5	0.6 - 0.7 μm	red
6	0.7 - 0.8 μm	near infrared
7	0.8 - 1.1 μm	near infrared

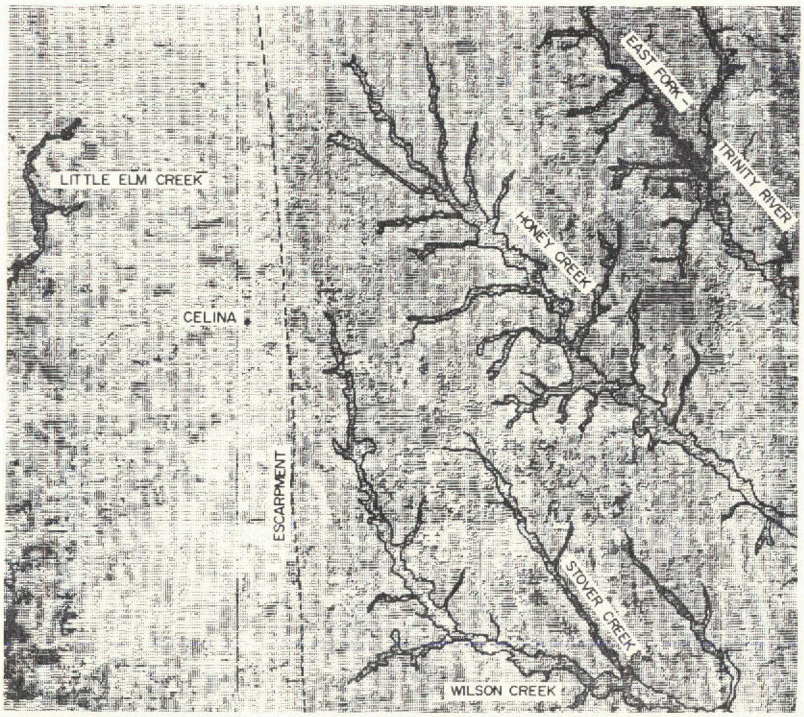
d. Results and Discussion

The use of multispectral scanner data enables production of quantitative reflectance measurements from each spectral channel, and for each resolution element or instantaneous field of view of the scanner system. The resolution of the ERTS-1 scanner is approximately 80 meters for elements in a scene having a contrast ration of 1:1.2. This means that the scanner at an altitude of approximately 900 km can detect, separate, or measure an area of two-thirds of a hectare if appropriate contrast exists. Where contrasts are extreme, even much smaller areas can be detected on scanner data.

By computer analysis of spectral data from Collin County, it was possible to map the gross natural drainage patterns of the County. In many cases, these spectral patterns also correspond closely to differences in soil associations and geologic parent materials (Figure 62). From spectral maps a prominent escarpment is readily identified in the western part of the county. This escarpment represents a division between soil associations, geologic materials, and types of agriculture. To the west of the escarpment, the average reflectance is considerably higher than east of the escarpment. Causes for these differences may be related to two factors for this particular set of data (Figure 63). First, the surface soils are lighter in color west of the escarpment. Second, wheat and grassland are the predominant cover west of the escarpment. Most of the vegetation on the heavier, darker soils east of the escarpment is cotton, grain sorghum, and wooded areas. At the times these spectral data were obtained, these areas were green, producing a relatively low spectral response. Grass pastures and wheat stubble west of the escarpment produced relatively high reflectance.

A very useful technique for interpreting multispectral data is to calculate the ratio between the relative reflectance in the visible channels and the relative reflectance from the reflective infrared. In this study the following ratio was used:





Figures 62 & 63. Gray-scale computer printouts, photographically reduced, showing classification of spectrally separable surficial features, such as drainage lines, vegetative cover types, and approximate position of Austin Chalk escarpment. Note increased detail at scale used in Figure 63 .

$$R = \frac{A + B}{D}$$

where, A = relative reflectance in Band 4 (0.5-0.6μm)
B = relative reflectance in Band 5 (0.6-0.7μm)
C = relative reflectance in Band 7 (0.8-1.1μm)

In general, for this set of data, low ratio values (<1) may be interpreted as green vegetation; values between 1.5 and 2.5 may be bare soil and/or plant residues. Water will produce yet higher ratio values. Different densities of green vegetative cover and percentages of exposed soil will produce intermediate ratio values between 1 and 2.

Although these results are preliminary, and the analysis of data was accomplished without benefit of ground observation data, quantitative spectral data from ERTS were very useful in separating and mapping gross surface features. The scene represented by the computer printout in Figure 63 is divided into eleven spectrally separable classes. One of the spectral classes is represented by the symbol "Q". This corresponds to the low reflectance areas of the drainageways. In general, these areas are covered with dense vegetation, trees, and bushes. The average R value for all Q's in the scene is 0.88. Within the drainageways interspersed with the symbol "Q" are individual "M's" or clumps of "M's". The average R value of M's in the scene is 1.79. This is indicative of bare soil or yellow, grassy spots in the drainageways. In the extreme northwest corner of this scene (Figure 63) is a concentration of "+'s" with an average ratio of 1.40. This represents a rangeland area covered with coastal Bermuda grass (<u>Cynodan dactylon</u>) which was yellow at the time of the ERTS pass.

These are examples of how quantitative spectral data may be used. Such data will become much more applicable when adequate ground observations provide for more complete interpretation.

e. <u>Summary and Conclusions</u>

An initial, rapid computer analysis of multispectral scanner data obtained from 900 km above the surface of the earth was used to delineate and map an area of 2,000+ km^2 into 12 spectrally separable classes. These classes were related to natural surface drainage patterns, soil associations, parent materials, and cultivated and natural vegetation.

These initial results were obtained with the analysis of data from only one overpass of ERTS-1. With the capability of obtaining multispectral data every eighteen days over the same study area, computer-implemented analysis of such sequential data should make it possible to delineate and map many soils and geologic features which are impossible to detect spectrally with satellite data obtained during the season of maximum vegetative cover.

6. FANNIN COUNTY, TEXAS STUDY

The following paper was presented at the University of Tennessee Remote Sensing Conference, University of Tennessee Space Institute, Tullahoma, Tennessee, 26-28 March 1973, under the title "An Interpretation of a Geologic Map of Fannin County, Texas, Prepared by ADP Techniques from ERTS MSS Data" by J. A. Henderson, Jr., J. V. Gardner, and J. E. Cipra.

a. Introduction

An area of relatively simple geology was chosen for testing the geologic mapping capabilities with ADP techniques on ERTS MSS data. MSS data were collected by the Earth Resources Technology Satellite on 25 July 1972. All data analysis was done at the Laboratory for Applications of Remote Sensing (LARS) using general analysis procedures developed at LARS.

b. Data Collection and Data Processing

The data used for this report are from the multispectral scanner and are in the form of digital computer compatible tapes. The bands of the multispectral scanner are in the visible and near infrared region of the spectrum: Band 4--0.50-0.60 μm, band 5--0.60-0.70μm, band 6--0.70-0.80μm and band 7--0.80-1.10 μm. The LARSYS software system is a package of computer programs, which have been designed to analyze and display remotely sensed multispectral data. Five major processing algorithms were used in this study: (1) CLUSTER, (2) STATISTICS, (3) CLASSIFYPOINTS, (4) PRINTRESULTS, and (5) NEWPHOTO. The CLUSTER processor is an unsupervised classifier that groups data vectors into spectrally distinct classes. Mean vectors and covariance matrices are calculated by the STATISTICS processor and are then used in the CLASSIFYPOINTS processor which performs a maximum likelihood Gaussian classification on a point-by-point basis over the entire area. Results from the above analysis are displayed using: (1) the PRINTRESULTS processor to make alphanumeric maps; and (2) the NEWPHOTO processor to display the results on the digital display.*

c. Geology

Fannin County, Texas is in the northwestern part of the Gulf Coastal Plain physiographic province and adjacent to the

*The Digital Image Display System receives an image from a System 360 computer, stores this data in a video buffer, and displays the image in a raster scanning mode on a standard television screen. An interactive capability to edit, annotate, or modify the image is provided through a light pen and a program function keyboard. An additional photographic copying capability is also provided.

Ouachita Province. Rocks of Cretaceous age crop out in the Fannin County area and dip south and southeast. A description and map of the rocks in Fannin County are presented in Figures 64 and 65.

d. Procedure

Two types of methods were used to select the training areas from the data for classification. The first type was unsupervised in that the classes were based entirely on spectral differences by use of a clustering algorithm. Manually selected training areas were utilized in the second type of classification using the published map for ground information.

A subset of Fannin County was chosen for classification using an unsupervised classifier (CLUSTER). The fifteen spectral classes defined by the CLUSTER processor were used as the basis for the first classification. A printout map and a photograph from the digital display were made, and these were evaluated.

A second unsupervised classification was made of a slightly larger area, specifying twenty classes. From this printout, areas were selected which contained six adjacent resolution elements in the same class. This was done to eliminate areas which contained points that were influenced by more than one type of surface cover. Using these areas, thirteen unsupervised classifications were performed to determine the number of spectral classes present. The separability information provided by the clustering processor indicated that there were twelve spectral classes in the data. The classes defined by the clustering processor were used to make classifications which were then displayed and evaluated.

Further analysis was done on the two classifications cited above using a procedure developed by the authors and other members of the LARS staff. Ratios of the reflected visible energy (mean values in bands 4 and 5) divided by the reflected infrared energy (mean values in bands 6 and 7) were calculated (4+5/6+7) and grouped according to numerical size. Classes which have similar ratios do not necessarily have similar intensities.

Two methods of manually selecting training areas were investigated: (1) training areas were selected from spectrally heterogeneous ground cover, and (2) training areas were selected from areas believed to be nonvegetated soil. A transparent overlay was made from the geologic map at the same scale as the computer printout map. Using this overlay, training areas

Age	Unit	Thickness (ft)	Description
Recent	Alluvium (Qal)	3±	Flood-plain and stream deposits
Pliestocene	Fluviatile terrace Deposits (Qt)	30	Terrace deposits generally sands and gravel
	Ozan Fm (Ko)	425±	Poorly bedded calcareous clay, weathers light brownish gray
	Austin Gp.		
	Roxton Limestone (Kr)	10	Sandy, red limestone
	Gober Chalk (Kg)	400±	Argillaceous Chalk weathers white
	Brownstown Marl (Kbr)	30	Massive calcareous clay, weathers light yellowish gray
	Blossom Sand (Kbl)	20	Quartz sand, weathers brown and red
Upper Cretaceous	Bonham Marl (Kbo)	400±	Marl and Clay, weathers light gray to yellowish gray
	Ector Chalk (Kec)	35	Chalk, weathers white
	Eagle Ford Fm. (Kef)	300-400	Medium to Dark Gray Shale
	Woodbice Fm		
	Templeton Mbr. (Kwt)	70-80	Gray shale
	Lewisville Mbr. (Kwl)	75-95	Glauconitic sandstone, gray to brown and yellowish brown
	Red Branch Mbr. (Kwr)	25-80	Sandstone, shale, and lignite, gray, brown, yellowish brown and grayish black

Figure 64. Geologic Column in Fannin County, Texas.

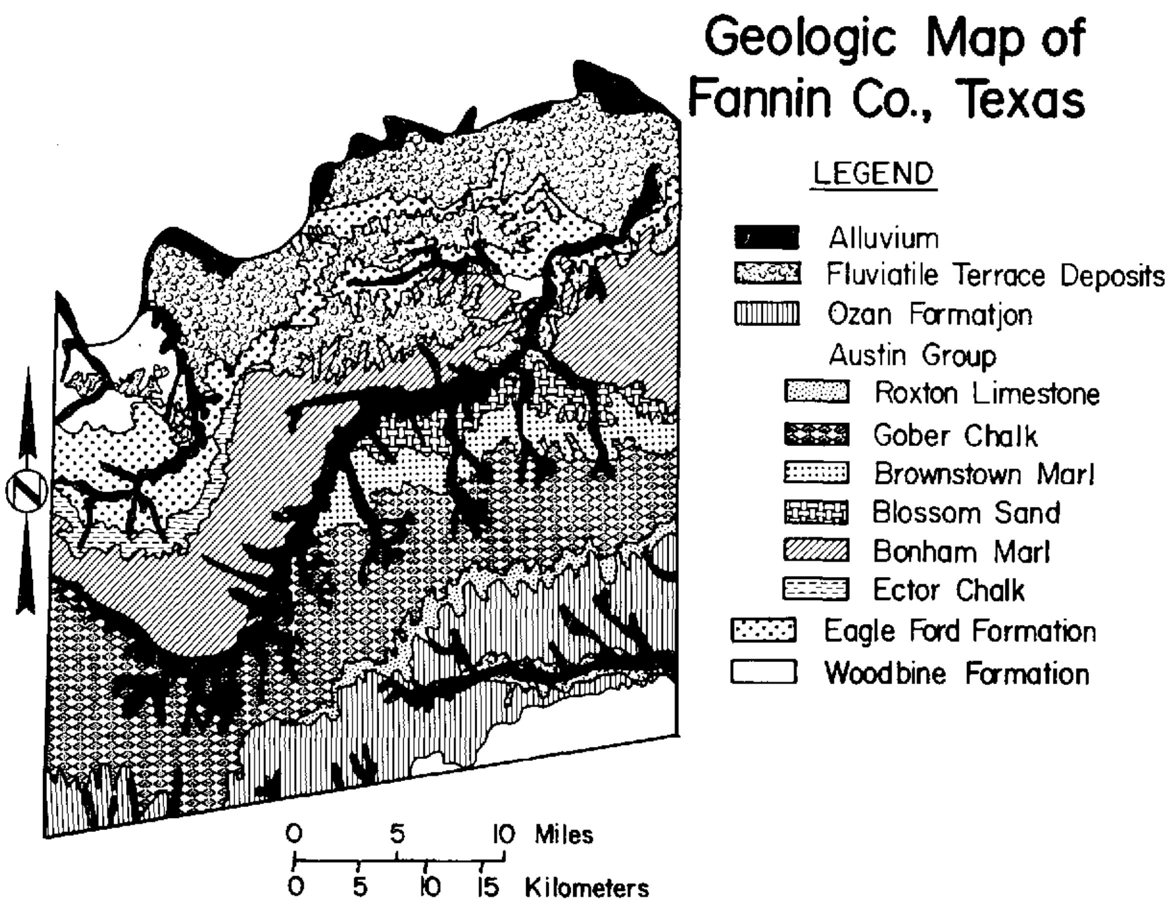


Figure 65. Geologic map of Fannin County, Texas.

were selected from each geologic unit, without regard to surface cover classification programs. The resulting classification was displayed in printout map form and also on the digital display.

Areas of nonvegetated soil, thought to be cultivated areas, were located and displayed on a printout map. The ratio procedure previously defined was used to identify these areas. Using the geologic overlay, training areas were chosen from nonvegetated areas within the known outcrop area of each rock type, and these were used as a basis for a classification. In addition, training areas of water and vegetation were used in the classification. Results of this classification were also displayed in a printout map and on the digital display.

e. Results

Classifications of the MSS data were displayed using a line printer and the digital display. Printout maps are generally unsatisfactory for large-scale visual analysis because of their size and resolution limitations. Conversely, the smaller pictures from the digital display allow the researcher the flexibility to make overlays, examine several classifications simultaneously, and compare features in each classification.

With the LARSYS system it is possible to evaluate a classification qualitatively or quantitatively (percent correct recognition). From a geological viewpoint, a classification was "good" if it showed boundaries between materials regardless of the percent correct recognition. Of the four classifications in this investigation, the most satisfactory results were obtained by using the twelve class unsupervised classification.

One of the most spectrally distinct materials in the MSS data is water. Large rivers, lakes, and some small streams can easily be identified in the classified area. Most of the smaller tributaries are lines with dense green vegetation. They can be visually recognized as streams because of the drainage pattern (dendritic to modified rectangular in Fannin County). Figure 66 shows many of the drainage features in Fannin County. This classification was produced by combining the twelve original classes on the basis of ratios. Several features are apparent on the photograph. A appears to be meander scars made by the Red River, B is an active meander, C is a tributary of one of the reservoirs in the county, and D and E are streams draining into the Red River.

Boundaries were drawn, between apparently different materials, on several of the digital display photos. When these drawn boundaries were compared with a geologic map of similar scale, it was apparent that most of the inferred boundaries were correct.

Figure 66. Drainage features in Fannin County, Texas from computer processed classification results.

Figure 67 shows the approximate location of mapped contacts between rock units (numbered, dashed lines) and boundaries drawn because of spectral differences (lettered, solid lines). These boundaries were drawn on the original twelve class classification. As can be seen on the photograph, lines A and C and part of lines D and E most nearly match with mapped contacts 1, 2, 3 and 4 respectively. The computer classification shows differences in material at lines B, F, G and H which were not mapped as rock contacts. The apparent discrepancies may be the result of topographic and/or land use effects. Lines A and B mark the approximate edges of a low plateau which may cause the difference in reflectance. Areas enclosed by lines H are thought to be dense green vegetation in the stream valleys.

f. Conclusions

Geologic reconnaissance mapping can be done using ADP techniques on MSS data for this area of Texas. In conjunction with the remote sensing data, the researcher should have at his disposal reliable ground data on which to base his conclusions. In some instances it may be possible to process the data before ground observations are made, and use the ground observations to verify boundaries eatablished by the computer or to help complete incorrectly or incompletely mapped areas.

The greatest problem associated with the geologic mapping using MSS data is that what is being mapped is not rock but ground cover. To cope with this problem, the researcher assumes that vegetation and soil are influenced by rock type and change only where the lithology changes. In nonagricultural areas where there is native vegetation, this assumption should hold.

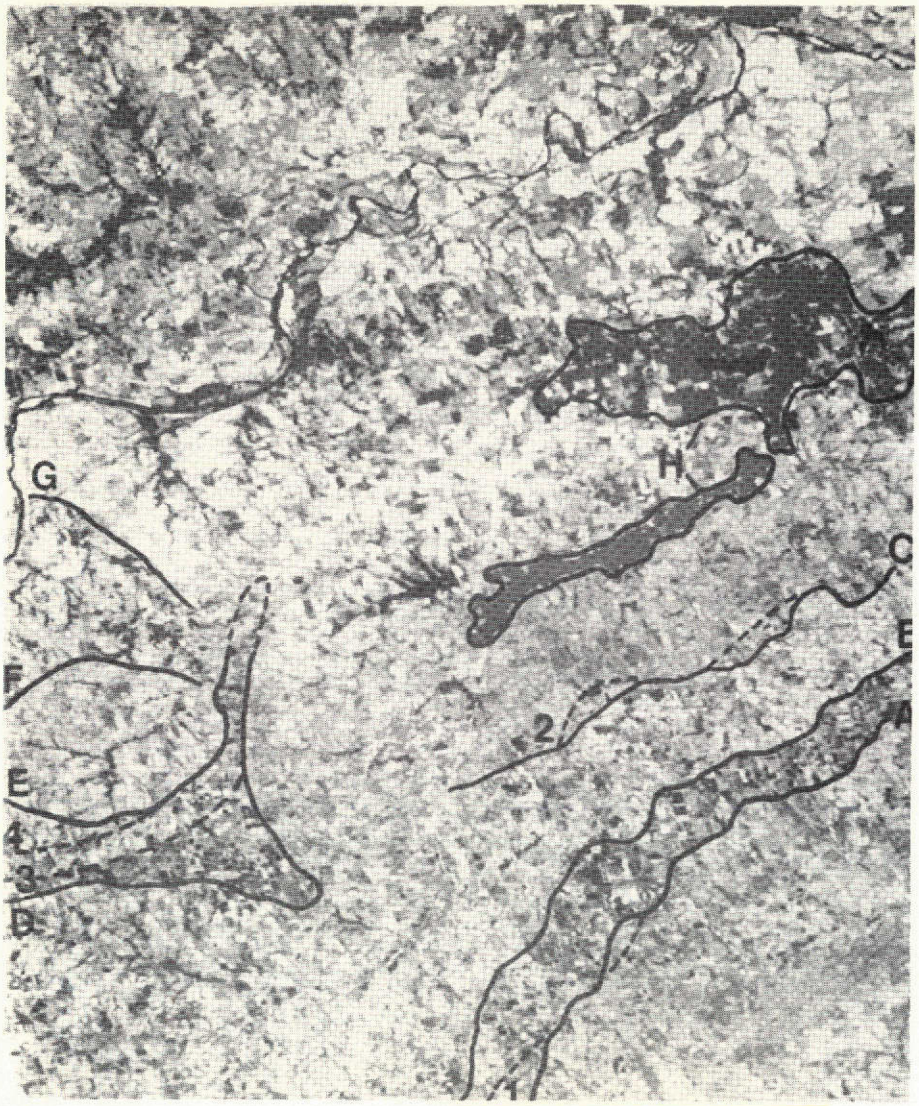


Figure 67. Geologic interpretation of a computer classification of Fannin County, Texas.

1. Contact between the Roxton Limestone and the Gober Chalk
2. Contact between the Gober Chalk and the Brownstown Marl
3. Contact between the Bonham Marl and the Ector Chalk
4. Contact between the Ector Chalk and the Eagle Ford Formation

7. SUPPORTING UNDERFLIGHT DATA

In support of ERTS contract NAS5-21773 three underflight missions were flown using a NASA operated NC-130 aircraft:

Mission	Date	Site	
213	10/14 Sept. 1972	238	Lubbock Regional Test Site
		329	Humboldt County, Iowa
		330	Greeley County, Kansas
		331	McPherson County, Nebraska
		332	Wells County, North Dakota
230	20 March 1973	238	Lubbock Texas Regional Test Site
238	14 May 1973	329	Humboldt County, Iowa
		330	Greeley County, Kansas
		331	McPherson County, Nebraska
		332	Wells County, North Dakota

Three types of sensors were used: two RC-8 cameras, one with color positive film and one with color infrared positive film; one Hassalblad camera with black and white positive film; and one 24 channel Bendix multispectral scanner. All data were taken at approximately 20,000 feet above ground level.

All photographic data were of good enough quality to be useful. The color (Figure 68) and color infrared (Figure 69) photographs for all test sites and all missions were the most useful underflight product for this investigation. These data were used for all test sites as a primary source of gorund information. The black and white positive transparencies (Figure 70), while being of good quality, were not used because of the completeness of the color photographic products.

Scanner data (Figure 71) were received for all test sites for mission 213. Some problems were associated with the 24 channel multispectral scanner data. The two major problems were that the data was noisy, i.e. bad data lines perpendicular to the flightline, and that the platform moved while data was being collected which gave the data a wavey nature (the plane was subject to excessive crab, roll, and pitch).

The scanner data was received after high quality ERTS scanner data had been received. In addition to problems in the data, some problems were encountered in the reformatting of the scanner data into a form compatible with the LARSYS data analysis system. When two of the original data tapes were combined to form one continuous strip of data, there were gaps or overlaps in data. Also the reformatted data were mirror images of ground features. Because of the problems of data quality, it was felt that the objectives of the contract could best be met by using the ERTS MSS data as the primary (sole) digital data source.

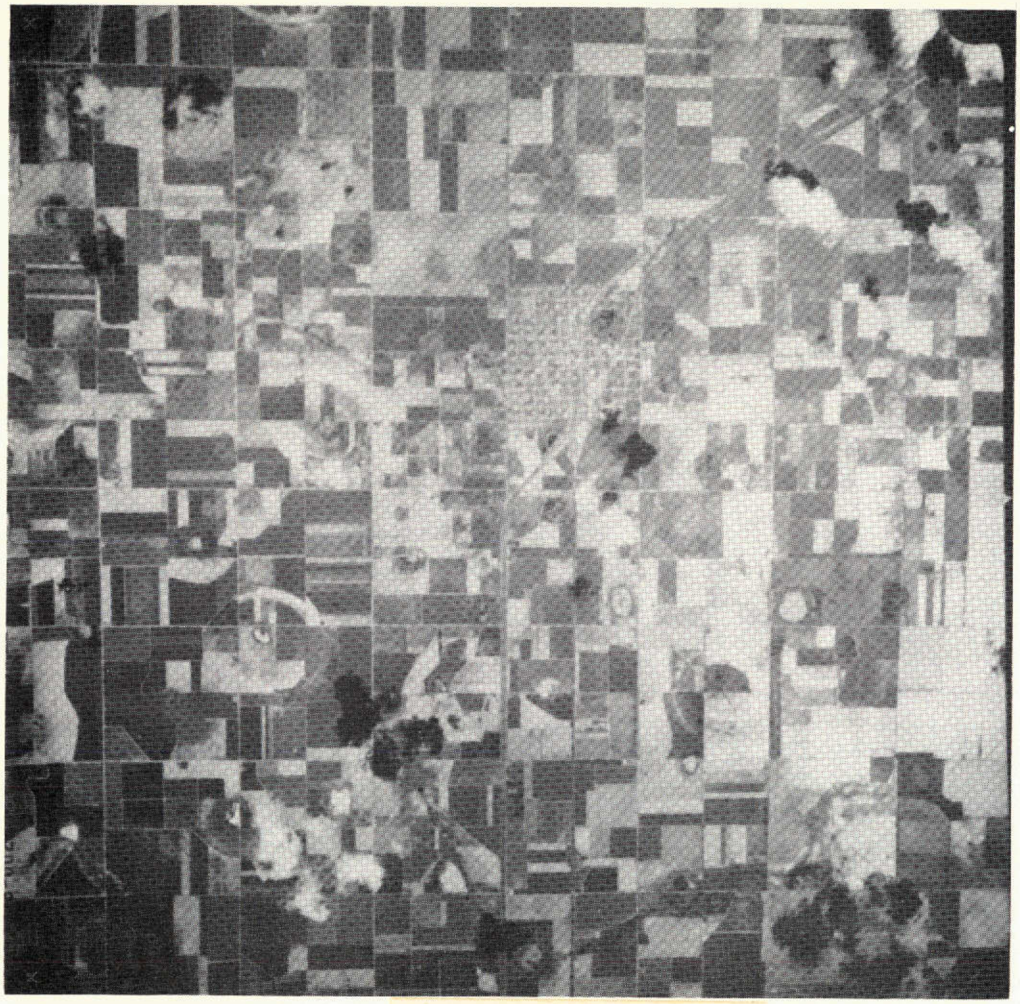


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Figure 68. Black and white copy of a color aerial photo of Hale Center, Texas, 10 September 1972.

Figure 69. Black and white copy of a color infrared aerial photo of Hale Center, Texas, 10 September 1972.

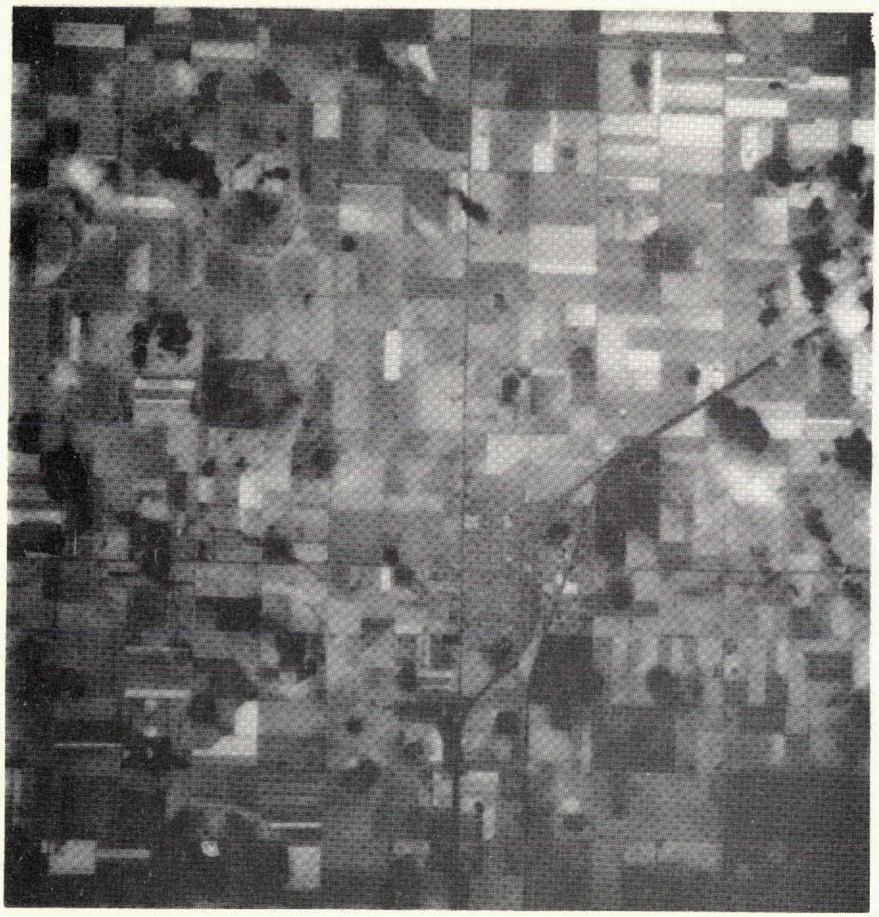

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Figure 70. Copy of black and white positive transparency of Hale Center, Texas, 10 September 1972.

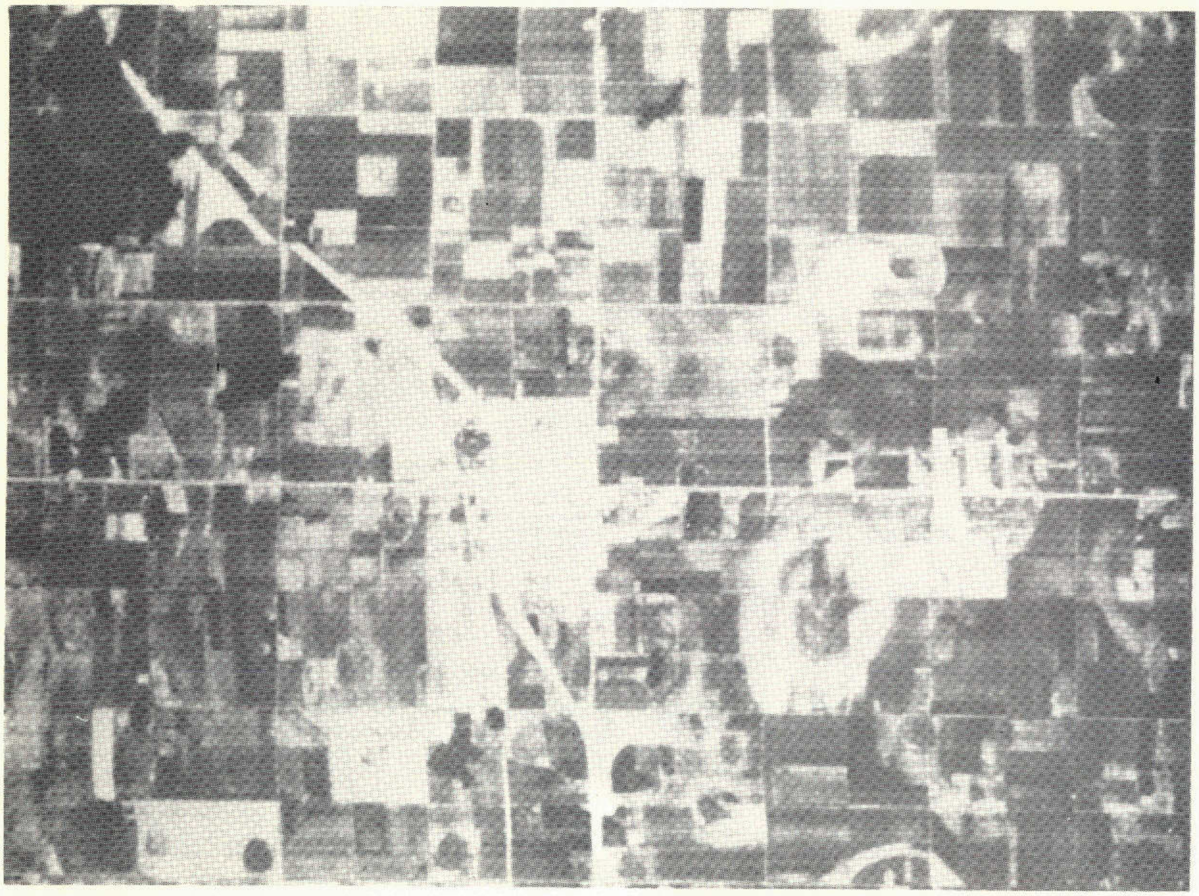

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Figure 71. Digital display of channel 9 (0.82-0.88μm) of Hale Center, Texas, 10 September 1972.

IV. CONCLUSIONS

A. GENERAL

The Laboratory for Applications of Remote Sensing has conducted studies under four ERTS-1 contracts. Together these four contracts have permitted the Laboratory to study a wide variety of earth surface features of test sites over a broad range of climate and geography. This extensive sampling of multispectral data from many dates and all seasons and from more than twenty test sites in almost as many states has provided the opportunity to support a strong analysis capability which developed new techniques of value to each of the contracts.

The results and conclusions included in this report are only part of a total Laboratory effort to develop computer-implemented techniques for analysis, interpretation and evaluation of ERTS-1 multispectral scanner data.

1. DATE OF DATA ACQUISITION

The utility of multispectral data is greatly dependent upon the time of data acquisition. This study revealed that ERTS data most suitable for delineating soils boundaries were not necessarily the best data for identification of crops. For the identification of summer annual crops ERTS data acquired late in the growing season (mid-July through September) provided best results. For winter small grains, the best time for identification is in winter or early spring or just prior to harvest time in summer. The most suitable time for obtaining ERTS data for studying soils and geologic features seems to be in late winter, spring, or early summer when a minimum amount of ground cover exists. The delineation of land use classes, both urban and rural, seems to be most easily accomplished spectrally late in a summer growing season.

2. GROUND OBSERVATION DATA

If other than very broad surface features (vegetation, bare soil, water) are to be spectrally identified and mapped with ERTS multispectral data, it is important to obtain an appropriate sampling of accurate ground observation data. In an analysis system such as that of LARS where the analyst can interact with the data during analysis, the accuracy and quality of the analytical results are many times closely related to the knowledge the analyst has of the study area. Ancillary information will benefit the analyst in training the computer and in evaluating or interpreting the results.

The ideal method of obtaining ground observation data is to have the analyst in the study area at the time of ERTS data acquisition. However, since it was not possible to have an analyst in the six test sites at the time of most ERTS passes, other methods of obtaining ground observations were employed.

It was concluded from this study that excellent ground observation data can be collected by interested residents of an area if adequate instructions have been provided for obtaining and reporting the information. Ground observations reported by volunteers in the Lubbock Regional Test Site proved to be very useful for training the computer. In other test sites the only source of ground information was aerial photography, maps, and other published information. It was found that aerial photos are useful for choosing training sets, particularly if the aerial photos were obtained within a reasonable time of the ERTS pass. Published soil surveys proved to be useful in identifying and mapping soils boundaries on ERTS data.

3. TECHNIQUES

These and other preprocessing procedures were developed at LARS but not directly supported by this contract.

a. Geometric Correction of ERTS Data

The geometric correction removes the distortion in the data caused by: (1) the earth's rotation, (2) path of the satellite, and (3) different vertical and horizontal scales. The data can also be rescaled so that it is approximately 1:24,000 scale on a line printer. This procedure allows the printout maps to be physically overlayed on 1:24,000 scale maps (7.5° USGS Topographic Maps) for more exact location of features within the data. A geometrically corrected product is more acceptable to the user community than a non-corrected output because it is similar to conventional aerial photos and maps.

b. Temporal Overlay of Data from More than One Date

The temporal overlaying of data developed at LARS combines data collected on two or more dates into one set of data with a one-to-one correspondence between points in all the data. There are several advantages to using overlayed data: (1) data from more than one date can be used to classify an area; (2) once training or test samples are located within the data they can be used for all dates in the overlayed run; (3) temporal change, on an individual point-by-point basis, can be assessed.

The most important contribution of data which has been temporally overlayed is that data from more than one date may be used in classifying an area. The combining of data from two or more dates will, in some cases, allow features to be identified which would not be identifiable on only one date. Once a training or test area has been located, the same coordinates can be used for all dates in the overlayed run. Analysis programs are being developed which will permit change to be obtained on a point-by-point basis.

B. SPECIFIC CONCLUSIONS FOR THIS PROJECT

1. VEGETATION IDENTIFICATION

Timely information can be obtained by using remote sensing methods to monitor and map vegetation. Wheat was identified and mapped in Greeley County, Kansas. Aerial photography was the only ground information which was available during the study. This photography aided in the training of the computer and in assessing classification results. Area estimates were made from this classification and indicated 77,000 hectares of wheat in Greeley County. This figure compares very favorably with the Statistical Reporting Service (USDA) estimate of 73,000 $\pm$ 5% hectares and can be obtained much faster.

Rangeland quality has been assessed in this report in Lynn County, Texas and McPherson County, Nebraska. This capability will provide important information on which one may base rangeland management policies.

Row crops can be identified, but the separation of various types of row crops depends to a large extent on which crops will be identified. It should be possible to identify almost all row crops if good quality ERTS data are obtained at the appropriate time. As a means of identifying row crops early in the season, bare soil can be mapped at the beginning of the growing season and estimates of row crop acreages can be made at that time. While this method does not give acreages for individual crops, it can give an estimate of the total area to be planted to summer annuals.

2. SOIL STUDIES

It was possible in this project, using remote sensing data, to map soil associations. The accuracy of soil association maps are primarily dependent on two factors: (1) the time of year the data were collected and (2) variability of the soils. The best time of year for mapping soils appears to be the early part of the growing season where there is little if any vegetative cover. As a general rule from this study, the greater the variability in the soil associations, the better chance there is for having an accurate map. Soil association maps produced from remote sensing data may not correspond to existing soils maps because the criteria that were used in the original mapping (e.g. topographic or cultural criteria) may not be reflected in the remote sensing data. At the present time, to obtain a spectral signature for soils which will be valid in widespread locations, it is necessary to develop more accurate methods of calibrating data and compensating for atmospheric effects.

3. GEOLOGIC STUDIES

Using ERTS MSS data in both digital and photographic forms it has been possible to identify the surficial geology. By making the assumption that vegetation and topography are influenced by geological materials, the geology of an area may be interpreted. In an area of limited vegetative cover the geology of an area can be determined. If the refief of an area is great enough and if there is coverage of the area on two consecutive ERTS passes (sidelap), it is possible to obtain stereoscopic viewing, which can be used in mapping the geology of an area. It should be noted that both soils and geological mapping require manual interpretation of the images or classifications and cannot be completely analyzed by machine.

4. LAND USE STUDIES

Several parts of this project deal with the mapping of land use. It is possible to produce a land use map for both urban and agricultural areas. Primary land use classes, such as urban, argiculture, forest, water, and wetlands can be identified. In most cases it is possible to differentiate some secondary classes. The success of land use mapping is influenced to a large extent by the amount of ground information that is available and the time of the year the data were collected. With machine processing techniques large areas can be mapped much faster than with the more conventional method of using aerial photography and manual interpretation.

In this project, it has been possible to identify and map vegetative, soil, geologic, and land use features.

V. RECOMMENDATIONS

This contract has provided a marvellous opportunity for the principal investigator and his colleagues to study the soils, vegetation, and water resources of the six project test sites. However, certain problems were encountered during the contract period. The following recommendations are made in hopes that such problems may be minimized in the analysis and interpretation of data from future earth resources satellite systems.

1. Delay in receipt of ERTS data. The lag time between data collection and data receipt at LARS was, in most cases, too long to allow for any valid ground observation data to be collected after examination of ERTS digital data. For many phases of the study of earth surface features it would have been desirable to examine the ERTS MSS data and then check specific sites in the field. It is recommended that the delay in transmitting computer compatible tapes to the user be kept to a minimum.

2. Important of photographic products. There were problems in receiving data in the format requested in the contract. Although most of the analysis at LARS is with machine processing of digital data, the 70mm b and w negatives of ERTS-1 data are very important in the analysis procedure. Initial inspection of the photographic products is used to evaluate the quality of data, i.e. to check for clouds and their location; to insure that the test site is included in the data; and to check for any unusual characteristics (snow, bad data lines, other features). This initial inspection is important so that only the digital data to be analyzed will be reformatted into a form compatible with the LARSYS processing system.

Many times photographic products have not been received or were received long after the digital data had been received. It is recommended that the design of future systems provide very rapid production and transmittal of photographic products to the user.

3. Importance of aircraft underflight data. Four of the six test sites studied under this contract had no provision for collection of ground observation data. Aircraft underflight data were used to extract ground information for those test sites which were not visited by LARS personnel. In general, the aerial color and color infrared transparencies obtained over the test sites were very useful. They were particularly helpful in identifying land uses and cover types for selection of training sets for computer analysis of digital data.

Under this contract data were requested from the NASA 24-band MSS scanner from the 10 and 14 September 1972 underflights. However, as stated in a previous section on supporting underflight data, the scanner data were not of the quality expected. For this reason, aircraft scanner data were not analyzed.

It is recommended that aircraft underflight support be provided in future ERTS-type research and applications. Good photographic coverage is most valuable for selection of training and test sites for machine analysis of ERTS MSS data.

VI. ACKNOWLEDGEMENTS

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Oscar L. Montgomery
Scott Sinnock
John Stockton
William Todd
H. P. Ulrich
Carl F. Walker

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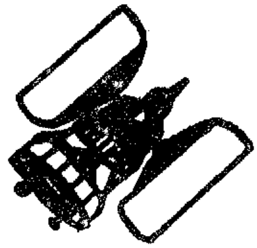
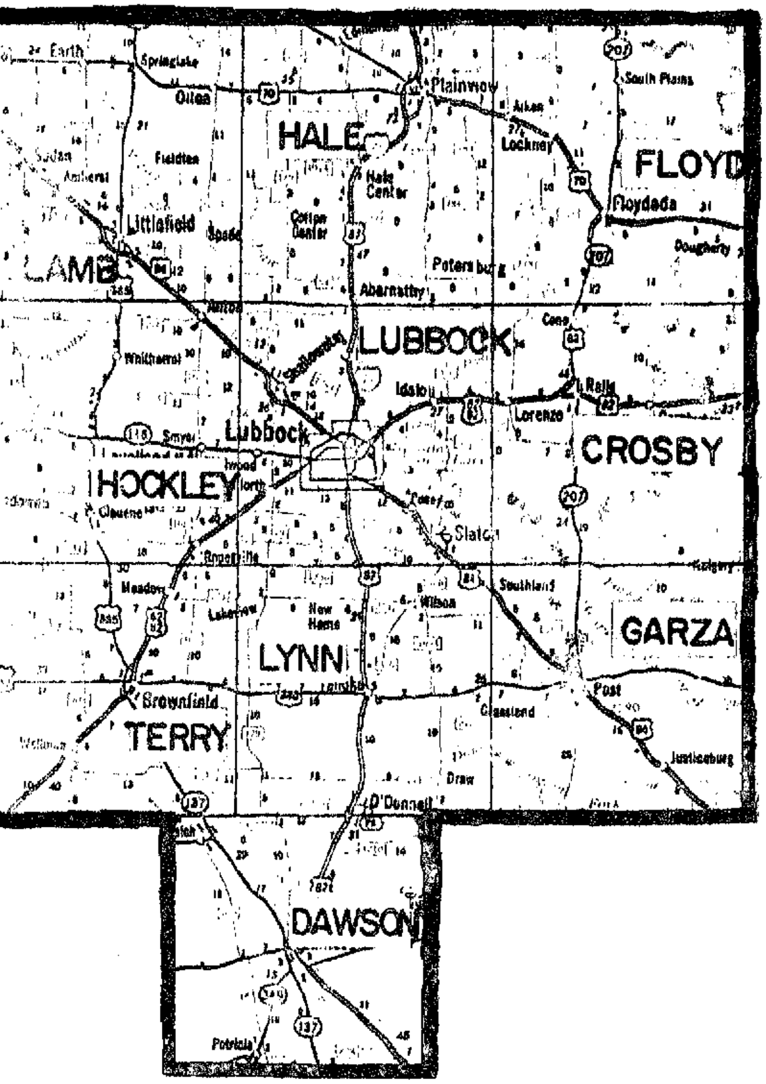
VIII. APPENDICES

APPENDIX A

Guidelines for Ground Observations-
Lubbock Regional Test Site

Guidelines for Ground Observations





Lubbock Regional Test Site

Earth Resources Technology Satellite Experiment

Coordinated by Laboratory for Applications of Remote Sensing, Purdue University

GUIDELINES FOR GROUND OBSERVATIONS

Lubbock Regional Test Site
Earth Resources Technology Satellite Experiment

Data obtained by sensors on ERTS as it passes over the Lubbock Regional Test Site every 18 days will be received by the Laboratory for Applications of Remote Sensing, Purdue University, as recorded electronic signals on magnetic tape. The data will be analyzed by computer.

In order to train the computer to identify and map different surface features of interest, it is necessary to have a sampling of accurate ground observations for use as a training set in machine processing. This is why you, the volunteer ground observer, are so important to the success of this experiment.

A number of suggestions are given herein to aid in the successful completion of ground observations each time ERTS obtains data over the Lubbock Regional Test Site.

WHEN TO MAKE OBSERVATIONS

ERTS-1 is scheduled to pass over the Lubbock Regional Test Site on the following dates:

August 16
September 3
September 21
October 9
October 27
November 14
.
.
.
until August 1973

We hope that you will be willing and agreeable to make observations along your road segment for each of the passes up to an through October 9. During the fall and winter months we will analyze and evaluate our procedures and results. Any necessary improvements and procedural changes will be made and reported to you in sufficient time for observations to begin in the spring of 1973.

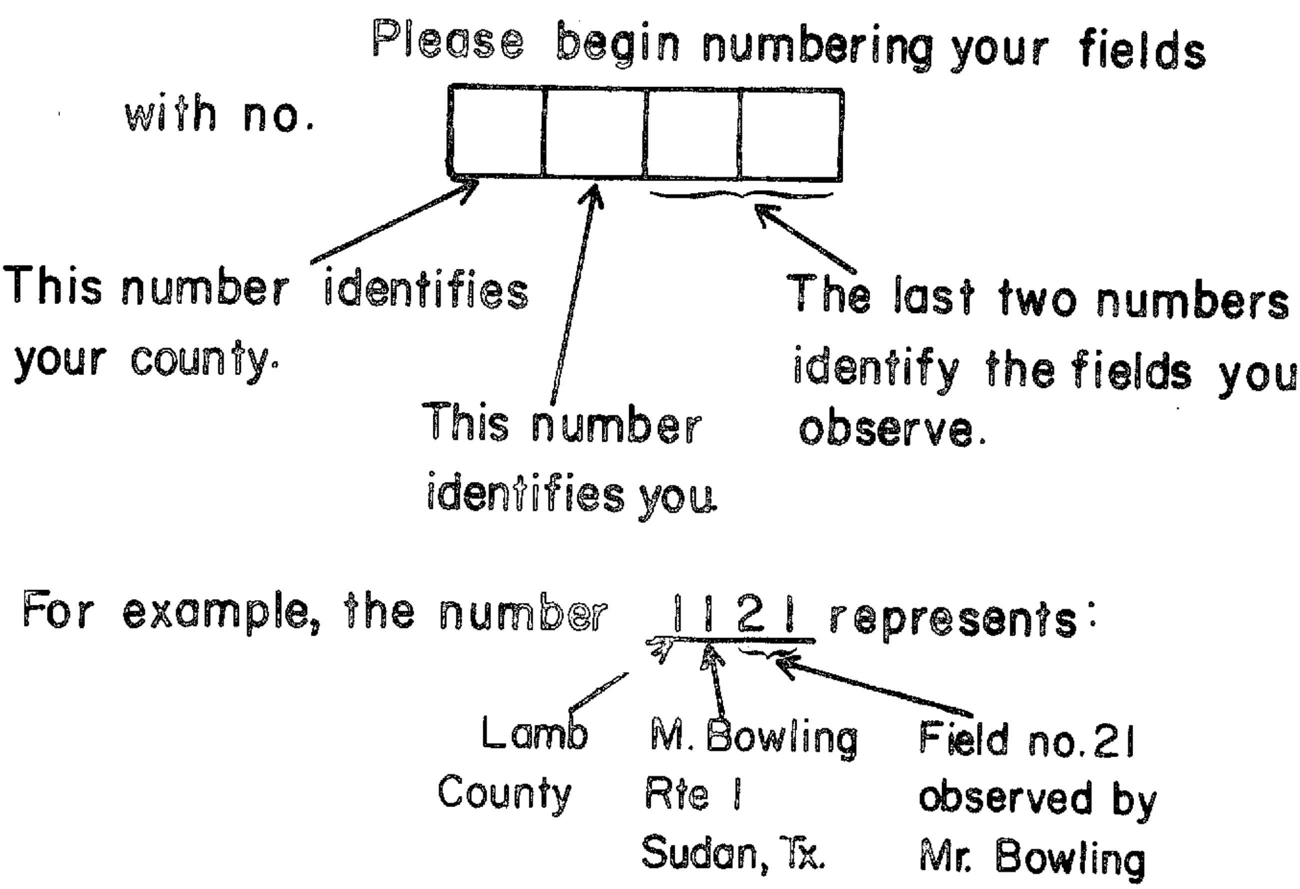
You will also be notified if there is any change in the dates of ERTS pass over of your county.

AREA TO BE OBSERVED

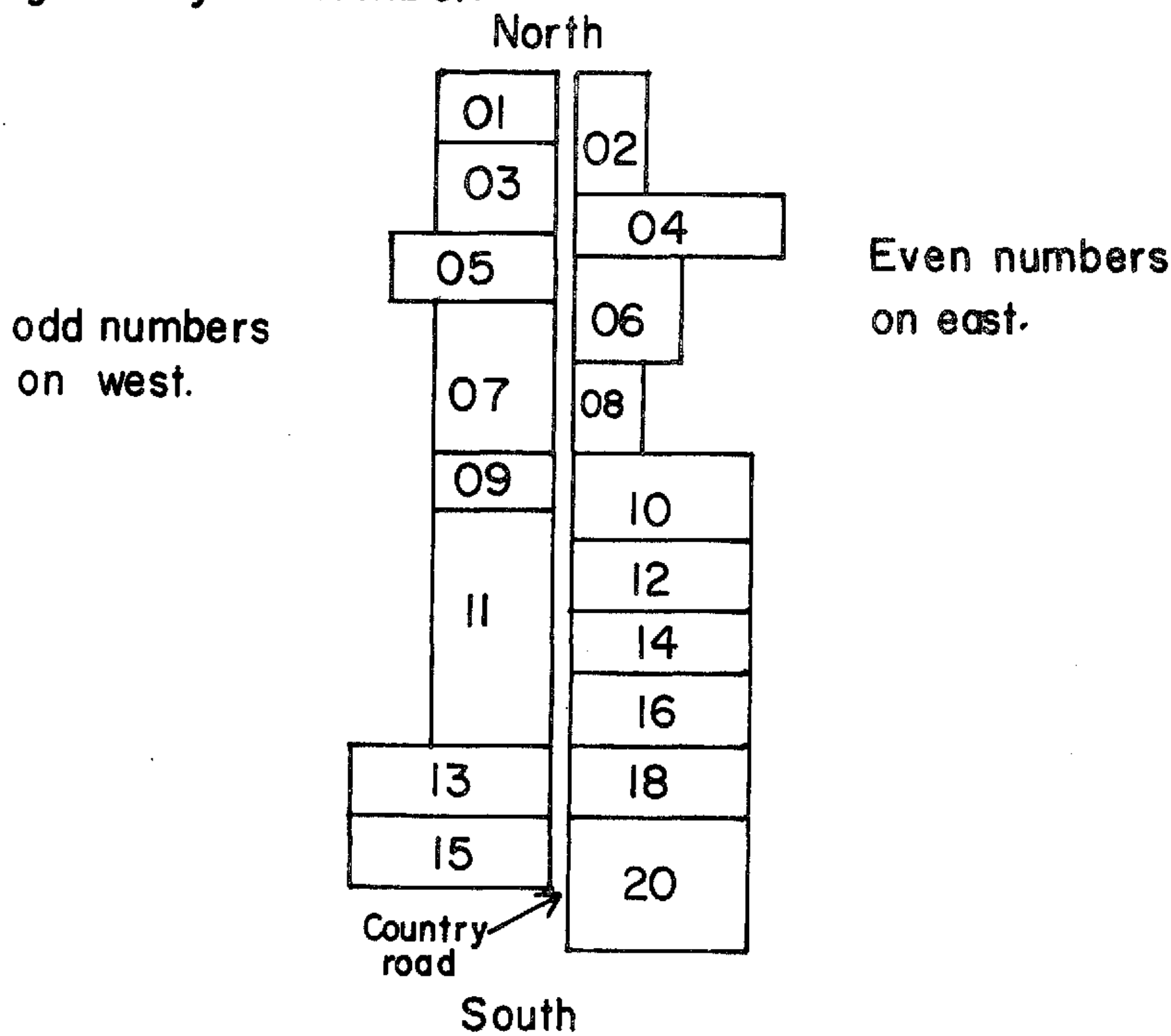
Each volunteer ground observer has been requested to make observations of every field (crop, pasture, farmstead, other) on each side of a specified segment of road. It is important that we have a map (can be rough drawing) of the area you are observing, showing the relative size, shape, and location of field and the field number.

METHOD OF NUMBERING FIELDS

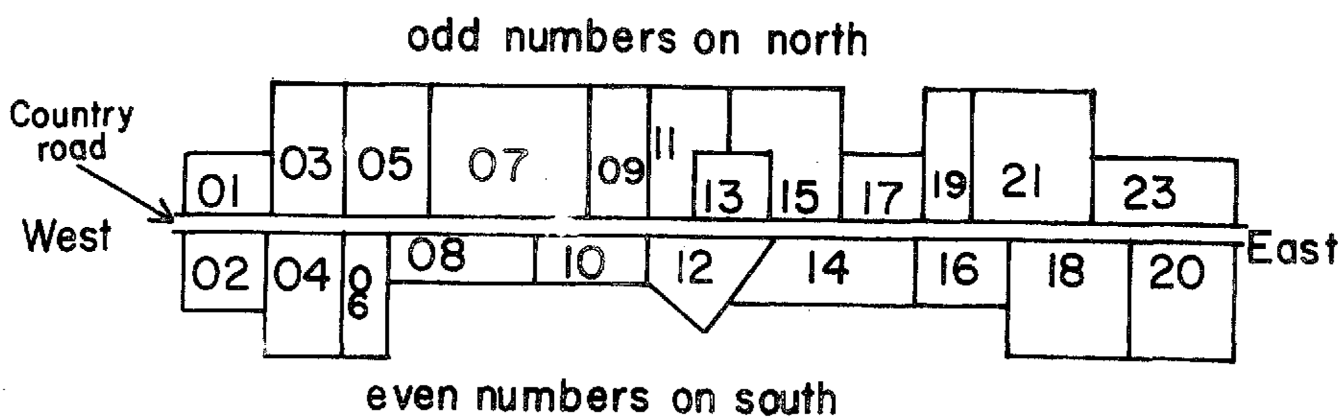
It is absolutely essential that your field numbering system correspond with ours because we must use your field number and observation data to train the computer.



If your road segment runs north-south, please number as follows, writing the field numbers as the last two digits of your number.



If your road segment runs east-west, please number as follows:



If you have other variations, the main consideration is to make sure that every field (crop, pasture, playa lake, weeded area, farmstead) which borders your road segment is numbered.

HOW TO MARK GROUND OBSERVATION FORM

Field No.: Every field to be observed in the 10 county Lubbock Regional Test Site must have a unique four digit number. Write the appropriate number at the top of each column on the Ground Observation Form.

First digit is for county:

Lamb	1	Crosby	6
Hale	2	Terry	7
Floyd	3	Lynn	8
Hockley	4	Garza	9
Lubbock	5	Dawson	0

Second digit is for the observer

Your number is __ __ __ __

Third and fourth digits are for the number you assign to a field.

1. Crop (land use) please place X in the appropriate blank.

2. Planting pattern: please place X in the appropriate blank.

3. Growing conditions: More than one condition may apply; place X in the appropriate blanks.

4. % Ground Cover (growing crop or crop residue): Mark one space only under this heading. Estimate the percent of the ground surface which is covered by green vegetation or crop residue.

5. Stage of Residue: Mark the appropriate boxes which will best indicate the stage of residue of the most recent crop if crop has been harvested.

6. Other conditions: Mark the boxes which best describe the surface soil and/or the growing crop.

7. Row direction: Self explanatory.

Example:

GROUND OBSERVATIONS
FOR ERTS EXPERIMENT

Date August 16, 1972

	Field No. 1101	Field No. 1102	Field No. 1103	Field No. 1104	Field No. 1105	Field No. 1106	Field No. 1107	Field No. 1108
1. Crop (Land Use)								
Wheat	X							X
Cotton		X			X			
Grain Sorghum (milo)						X		
Soybeans								
Forage Sorghum							X	
Alfalfa			X	X				
Pasture								
Farmstead								
Other								
2. Planting Pattern								
Solid			X	X			X	
2 and 1	X	X						X
2 and 2					X			
2 and 4						X		
4 and 4								
4 and 2								
Double Row								
Drilled								
Other								
3. Growing Conditions								
Dryland	X		X	X			X	X
Irrigated		X				X		
Pre-Boot								
Boot								
Heading								
Square								
Bloom					X			
Mature								
Other								

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OTHER CONSIDERATIONS

If you have any questions regarding these guidelines or this experiment, please consult your County Agent.

GROUND OBSERVATIONS
FOR ERTS EXPERIMENT

	Field No.	Field No.	Field No.	Field No.	Field No.	Field No.	Field No.	Field No.
1. Crop (Land Use)								
Wheat								
Cotton								
Grain Sorghum (milo)								
Soybeans								
Forage Sorghum								
Alfalfa								
Pasture								
Farmstead								
Other								
2. Planting Pattern								
Solid								
2 and 1								
2 and 2								
2 and 4								
4 and 4								
4 and 2								
Double Row								
Drilled								
Other								
3. Growing Conditions								
Dryland								
Irrigated								
Pre-Boot								
Boot								
Heading								
Square								
Bloom								
Mature								
Other								
4. % Ground Cover (Growing Crop/Residue)								
0								
25								
50								
75								
100								
5. Stage of Residue								
Harvested								
Pasture								
Shredded								
Disked								
Moldboarded								
Other								
6. Soil Conditions								
Fresh Plowed								
Crusted								
Active Wind Erosion								
Dry (Surface Soil)								
Wet (Surface Soil)								
Other								
7. Crop Conditions								
Clean (Few Weeds)								
Weedy								
Succulent (Plants)								
Stress (Crop Wilted)								
Visible Hail Damage								
Other								
8. Row Direction								
North-South								
East-West								
Contour								
Other								

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Ground Observer ______________________ County ____________ ________
(Name) Date

APPENDIX B

Master List:

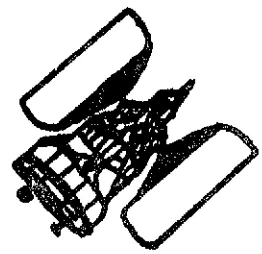
County Agricultural Agents and Cooperating Ground Observers-Lubbock Regional Test Site

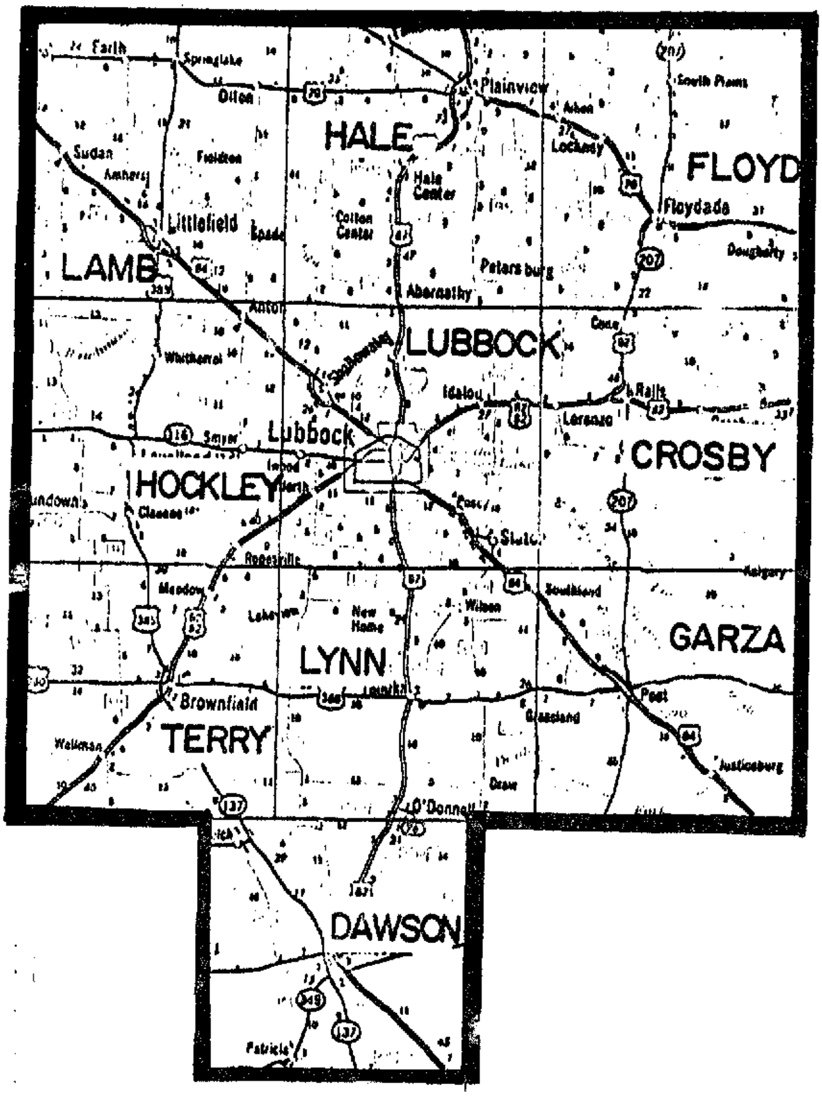
Master List

County Agricultural Agents

And

Cooperating Ground Observers





Lubbock Regional Test Site

Earth Resources Technology Satellite Experiment
(National Aeronautics and Space Administration)

Coordinated by Laboratory for Applications of Remote Sensing, Purdue University
August 1972

Coordinator of the Lubbock Regional Test Site Experiment:

ID. NO.		Telephone (H=Home, O=Office)
	Dr. Marion F. Baumgardner LARS Purdue University W. Lafayette, Ind. 47907	317/749-2052 (O) 317/743-2226 (H)
	District Extension Agent: Mr. Billy Gunter RR 3, Box 213AA Lubbock, Texas 79401	806/763-9451 (O)
	<u>Crosby County, Texas (County No. 6)</u>	
	<u>County Agent</u>	
60	Joe E. Wise Box 409 Crosbyton, Texas 79322	806/675-2003 (O)
	<u>Cooperators</u>	
61	Otis English Route 2 Crosbyton, Texas 79332	806/697-2644 (H)
62	Max Joiner Box 515 Lorenzo, Texas 79343	806/634-5956 (H)
63	Wilbur Leon Route 1 Petersburg, Texas 79250	806/667-2279 (H)
64	Lawrence McDowell Route 1 McAdoo, Texas 79243	806/697-2483 (H)
65	Johnny Nunley Route 1 Ralls, Texas 79357	806/649-2788 (H)
66	Charlie Wheeler Box 599 Crosbyton, Texas 79322	806/675-2240 (H)
	<u>Dawson County (County No. 0)</u>	
	<u>County Agent</u>	
00	Lee Roy Colgan Courthouse Lamesa, Texas 79331	806/872-7479 (H) 806/872-3444 (O)

Cooperators

01	Leon Cohorn 209 Highland Drive Route D Lamesa, Texas 79331	806/872-5616 (H)
02	Eldon Moody Box 56 Lamesa, Texas 79331	806/872-7597 (H)
03	Arthur Nolan 100 No. 20th Street Lamesa, Texas 79331	806/872-3767 (H)
04	Ronald Raney Box 385 Welch, Texas 79377	806/489-3864 (H)
05	Harold Vogler Route A Lamesa, Texas 79331	806/462-5731 (H)
06	Cartis White Route B Lamesa, Texas 79331	915/353-4816 (H)

Floyd County (County No. 3)

County Agent

30	Doyle G. Warren Box 520 Floydada, Texas 79235	806/983-2806 (O)

Cooperators

31	Eugene Beedy South Plains, Texas 79258	806/983-2951 (H)
32	Craig Edwards Route 1 Floydada, Texas 79235	806/983-2675 (H)
33	Mickey D. Hammonds Route 2 Floydada, Texas 79235	
34	Vernie Moore Route 4 Floydada, Texas 79235	806/983-2006 (H)
35	Weldon Pruitt Route 3 Floydada, Texas 79235	806/983-2040 (H)

36 Albert Scheele
Route 1
Lockney, Texas 79241 — 806/296-7085 (H)

Garza County (County No. 9)

County Agent

90 R. Syd Conner
Courthouse
Post, Texas 79356 — 806/495-2050 (O)

Cooperators

91 John Boren
Box 115 — 806/629-4335 (H)
Justiceburg, Texas 79330 — Verbena

92 Dale Cravy
Star Route
Post, Texas 79356 — 806/996-3664 (H)

93 C. R. (Pete) Lancaster
Route 2
Post, Texas 79356 — 806/996-3664 (H)

94 B. L. Thomas
Route 2 — 806/996-2804 (H)
Post, Texas 79356 — Southland

95 Jerry Thuett
Route 3 — 806/495-3017 (H)
Post, Texas 79356 — Post

Hale County (County No. 2)

County Agent

20 Ollie F. Liner
Box L
Plainview, Texas 79072 — 806/296-7466 (O)

Cooperators

21 S. R. Heard
Route 1 — 806/667-3922 (H)
Plainview, Texas 79072 — Petersburg

22 Joe Leach
Route 3
Plainview, Texas 79072 — 806/296-9344 (H)

23 Dr. Tom Longnecker
Box 1870 — 806/293-5720 (H)
Plainview, Texas 79072 — 806/889-3315 (O)

24 Ralph B. Mabry
Route 2, Box 14
Petersburg, Texas 79250 — 806/667-3754 (H)

25 E. E. Masters
Route 1 — 806/879-4464 (H)
Hale Center, Texas 79041 — Cotton Center

26 E. J. Pope, Jr.
Route 2 — 806/757-2815 (H)
Abernathy, Texas 79073 — County Line

<u>Hockley County (County No. 4)</u>

<u>County Agent</u>
40 Bill R. Taylor
Courthouse Annex
Levelland, Texas 79336 — 806/894-3159 (O)

<u>Cooperators</u>
41 N. V. Fred
Route 3
Levelland, Texas 79336 — 806/894-5889 (H)

42 Bill Jackson
Route 1
Levelland, Texas 79336 — 806/297-4124 (H)

43 Gene Nugent
County Agents Office
Levelland, Texas 79336 — 806/894-3159 (H)

44 E. L. Schlottman
Route 3
Levelland, Texas 79336 — 806/933-2788 (H)

45 Bill Thompson
Citizens Coop Gin, Route 1
Shallowater, Texas 79363 — 806/997-4535 (H)

<u>Lamb County (County No. 1)</u>

<u>County Agent</u>
10 Buddy C. Logsdon
P. O. Box 432 — 806/385-3733 (H)
Littlefield, Texas 79339 — 806/385-4004 (O)

<u>Cooperators</u>
11 Marvin Bowling
Route 1
Sudan, Texas 79371 — 806/933-2451 (H)

12 Nollie Embry
Route 1
Amherst, Texas 79312 — 806/385-4132 (H)

13	Jack Feagley Star Route 2 Littlefield, Texas 79339	806/262-4441 (H)
14	Norman Hinchliffe Box 375 Earth, Texas 79031	806/257-3762 (H)
15	Fred Long P. O. Box 478 Olton, Texas 71064	806/285-2281 (H)
16	Benny Pickerell 230 E. 23rd Street Littlefield, Texas 79339	806/385-3763 (H)
17	Arlen Simpson 115 E. 20th Street Littlefield, Texas 79339	806/385-5890 (H)

Lubbock County (County No. 5)

County Agent

50	Paul E. Gross County Extension Office Lubbock, Texas 79401	806/763-5351 (O) Ext. 235

Cooperators

51	Arnold Chauncey 3802 25th Street Lubbock, Texas 79410	806/799-0697 (H)
52	W. B. Criswell Route 1 Idalou, Texas 79329	806/892-2090 (H)
53	F. H. Griffin Route 1, Box 67 Slaton, Texas 79364	806/828-3065 (H)
54	Milton Kirksey Box 266 Wolfforth, Texas 79382	806/799-0010 (H)
55	Dr. Charles W. Wendt Agricultural Research and Extension Center Route 3 Lubbock, Texas 79401	806/763-9451 (O)
56	Charles W. Woods Route 2, Box 109 Lubbock, Texas 79415	806/762-8697 (H)

Lynn County (County No. 8)

County Agent

80	William B. Griffin Box 668 Tahoka, Texas 79373	806/998-4650 (O)

Cooperators

81	Harold T. Barrett O'Donnell, Texas 79351	806/428-3301 (H)
82	Elbert Crawford Route 2 Tahoka, Texas 79373	806/439-5185 (H)
83	Tom Mason Route 1 Tahoka, Texas 79373	806/327-5632 (H)
84	Howard Moore Route 2 O'Donnell, Texas 79351	806/465-3404 (H)
85	Lit H. Moore Route 1 Wilson, Texas 79381	806/863-2593 (H)
86	Jiggs Swann Route 1 Wilson, Texas 79381	806/996-2691 (H)

Terry County (County No. 7)

County Agent

70	James A. Foy Terry County Courthouse Brownfield, Texas 79316	806/637-2864 (H) 806/637-4060 (O)

Cooperators

71	Ronnie Brooks Box 136 Welch, Texas 79377	806/489-3832 (H)
72	Earl Brown, Jr. 1304 E. Cardwell Brownfield, Texas 79316	806/637-6662 (H)
73	Gerald Jordan Route 4 Brownfield, Texas 79316	806/585-2267 (H)

74	Gordon Patton 1312 E. Reppto Brownfield, Texas	79316	806/637-3730 (H)
75	Gary Tatum Route 1 Brownfield, Texas	79316	806/585-4111 (H)
76	Billy Yeatts Route 4 Brownfield, Texas	79316	806/522-3977 (H)

APPENDIX C

List of Publications from Central States Contract

PUBLICATIONS

Baumgardner, M. F. "Use of ERTS-1 in Agriculture, Forestry, and Other Vegetation Surveys," 54th Annual Meeting of the American Geophysical Union, Washington, D. C. 16-20 April 1973.

Baumgardner, M. F. and James A. Henderson, Jr. "Remote Sensing for Arid Lands Development," CONACYT-AAAS Symposium on Deserts and Arid Lands, Mexico City, Mexico, June 1973.

Baumgardner, M. F., James A. Henderson, Jr., and LARS Staff. "Mapping Soils, Crops, and Rangelands by Machine Analysis of Multitemporal ERTS-1 Data," Symposium on Significant Results Obtained from Earth Resources Technology Satellite-1, National Aeronautics and Space Administration, Washington, D. C. 10-13 December 1973.

Baumgardner, M. F., S. J. Kristof, and James A. Henderson, Jr. "Identification and Mapping of Soils, Vegetation, and Water Resources by Computer Analysis of ERTS MSS Data." Symposium on Significant Results Obtained from Earth Resources Technology Satellite-1, Goddard Space Flight Center, Greenbelt, Maryland, 5-9 March 1973.

Baumgardner, M. F., S. J. Kristof, W. N. Melhorn. "Mapping of Soils and Geologic Features with Data from Satellite-Borne Multispectral Scanners," 10th International Congress of Soil Science, Moscow, USSR, to be presented 12-20 August 1974; currently available as LARS Information Note 110872.

Henderson, James A. Jr., M. F. Baumgardner, and C. F. Walker. "Preparing Resource Inventories in the Southern Great Plains by Machine-Processing of ERTS-1 Multispectral Data," Fourth Annual Conference on Remote Sensing of Arid Lands Resources and Environments," Tucson, Arizona, 14-16 November 1973.

Henderson, James A., J. V. Gardner, and J. E. Cipra. "An Interpretation of a Geologic Map of Fannin County, Texas Prepared by ADP Techniques from ERTS MSS Data," Second Annual Remote Sensing of Earth Resources Conference, University of Tennessee Space Institute, Tullahoma, Tennessee, 28-26 March 1973.

Kristof, S. J. and M. F. Baumgardner. "Mapping of Soil Patterns with Multispectral Data from Earth Resources Technology Satellite," 89th Annual Meeting of Indiana Academcy of Sciences, Indianapolis, Indiana, 25-27 October 1973.

MacLeod, N. H. and M. F. Baumgardner. "Spectral Sensing of the Earth from Space," Agronomy Abstracts. Annual Meetings of American Society of Agronomy, Miami Beach, Florida, 29 October- 3 November 1972.

Melhorn, W. N., S. Sinnock, and O. L. Montgomery. "Analysis of Land Use-Land Form Relations from ERTS-1 Imagery, Sand Hills Region, MCPherson County, Kansas," Third Annual Remote Sensing of Earth Resources Conference, University of Tennessee Space Institute, Tullahoma, Tennessee, 25-27 March 1974.

Montgomery, O. L. and Emil Horvath. "Computerized Mapping of Water and Vegetation Using Satellite Imagery," Indiana Academy of Sciences, Indianapolis, Indiana, 1974 (in preparation).

Stockton, J. and J. Ahlrichs. "The Reflectance Differences of Mollisols Noted in Satellite Imagery," Soil Science Society of America Proceedings (in preparation).

Stockton, J., John Ahlrichs, Carl Walker, and M. F. Baumgardner. "Identification and Areal Measurement of Wheat from ERTS Imagery by Computer Enhancement Techniques," Agronomy Journal. (in preparation).

APPENDIX D

Image Descriptor Forms

ERTS IMAGE DESCRIPTOR FORM

(See Instructions on Back)

DATE March 1, 1973

PRINCIPAL INVESTIGATOR M. F. Baumgardner

GSFC UN630

ORGANIZATION

NDPF USE ONLY
D
N
ID

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS* Agricult	Soils	Water	DESCRIPTORS
1069-15585 MD	x			Urban
1044-16595 MD	x			
1086-15532 MD	x	x	x	
1078-16524 MD	x	x	x	
1114-16532 MD	x	x	x	
1132-16532 MD	x	x	x	
1002-16312 MD	x	x	x	Geologic Features
1017-16093 MD	x	x	x	Geologic, Urban

*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

MAIL TO ERTS USER SERVICES
CODE 563
BLDG 23 ROOM E413
NASA GSFC
GREENBELT, MD. 20771
301-982-5406

ERTS IMAGE DESCRIPTOR FORM

(See Instructions on Back)

DATE May 1, 1973

PRINCIPAL INVESTIGATOR M. F. Baumgardner

GSFC UN630

ORGANIZATION

NDPF USE ONLY
D
N
ID

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS* Sand dunes		River	DESCRIPTORS
1134-17052 MD	x			Playa
1133-16593 MD	x		x	Oil field Irrigation
1133-17000 MD			x	Anticlines Dome Lava flows
1132-16541 MD			x	Anticlines Dendritic drainage
1133-16591 MD				Rangeland Circular irrigation
1153-17105 MD			x	City Air field
1024-16522 MD				Agriculture Playas Urban
1025-16580 MD				Agriculture Irrigated Areas

*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

MAIL TO ERTS USER SERVICES
CODE 563
BLDG 23 ROOM E413
NASA GSFC
GREENBELT, MD. 20771
301-982-5406

ERTS IMAGE DESCRIPTOR FORM

(See Instructions on Back)

NDPF USE ONLY
D
N
ID

DATE August 1973

PRINCIPAL INVESTIGATOR Baumgardner, M. F.

GSFC UN 630

ORGANIZATION Laboratory for Applications of Remote Sensing

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS* urban	agric.	water	DESCRIPTORS
1078-16524 1078-16522	x x	x x	x x	Playa Cotton - irrigated and dry Ecarpment Fluviatile Plain
1114-16534		x		Clouds, Sand Dunes Oil Field
1114-16532	x	x	x	Playa, Escarpment
1114-16541				Anticline, River Bed Fault
1132-16530	x	x	x	Escarpment, Playa
1133-16591	x	x		Rangeland, Oil Field
1132-16532	x	x	x	Escarpment, Playa
1132-16541				Anticline, River Fault
1133-17000	x	x	x	Igneous Rocks, Fault
1133-16593	x	x	x	River, Sand Dunes
1024-16525	x	x	x	Playa, Escarpment
1006-16522	x	x	x	Playa, Escarpment
1024-16522	x	x	x	Playa, Escarpment
1069-15585	x	x		Corn, Pasture, Soil
1177-15593	x	x	x	Ground Moraine
1044-16595		x	x	River, Ablation Moraine, Ground Moraine, Lake Bed

*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES OW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRI E THE TERM UNDER THE DESCRIPTORS COLUMN).

MAIL TO
ERTS USER SERVICES
CODE 563
BLDG 23 ROOM E413
NASA GSFC
GREENBELT, MD. 20771
301-982-5406

ERTS IMAGE DESCRIPTOR FORM

(See Instructions on Back)

DATE ______

PRINCIPAL INVESTIGATOR ______

GSFC ______

ORGANIZATION ______

NDPF USE ONLY

D ______

N ______

ID ______

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
	Urban	Agric.	Water	
1057-16323		x	x	Soils, Lake
1061-16564		x	x	Soil
1007-16563		x	x	Soil

*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

MAIL TO ERTS USER SERVICES
CODE 563
BLDG 23 ROOM E413
NASA GSFC
GREENBELT, MD. 20771
301-982-5406

GSFC 37-2 (7/72)

ERTS IMAGE DESCRIPTOR FORM

(See Instructions on Back)

DATE September 1973

PRINCIPAL INVESTIGATOR M. F. Baumgardner

GSFC UN630

ORGANIZATION LARS/Purdue University

NDPF USE ONLY

D

N

ID

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
	Ag	Soils	Urban	
1044-16595	x	x	x	
1057-16323	x	x		
1079-16583	x	x	x	
1007-16563	x	x		
1296-17005	x	x		Lakes Clouds
1330-16524	x	x	x	Rivers Escarpment
1330-16531	x	x	x	Lakes Escarpment
1348-16523	x	x	x	Escarpment Rivers
1348-16525	x	x	x	Lakes Escarpment

*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES ' OW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

MAIL TO ERTS USER SERVICES
CODE 563
BLDG 23 ROOM E413
NASA GSFC
GREENBELT, MD. 20771
301-982-5406

GSFC 37-2 (7/72)

ERTS IMAGE DESCRIPTOR FORM
(See Instructions on Back)

NDPF USE ONLY
D
N
ID

DATE November 1, 1973

PRINCIPAL INVESTIGATOR M. F. Baumgardner

GSFC UN 630

ORGANIZATION Laboratory for Applications of Remote Sensing

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS* urban	range	wheat	DESCRIPTORS
1313-16563 CCT		x		Blow-outs
1331-16571 CCT		x	x	Fallow
1321-15593 CCT	x		x	Row crops, bare soils, forest
1357-15590 CCT	x			Corn, soybeans
1285-15595				Reservoir Bare soil
1330-16531	x	x	x	Irrigated cotton Dryland cotton Playas

NOT REPRODUCIBLE

*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

MAIL TO ERTS USER SERVICES
CODE 563
BLDG 23 ROOM E413
NASA GSFC
GREENBELT, MD. 20771
301-982-5406

GSFC 37-2 (7/72)

THE FOLLOWING PAGES ARE DUPLICATES OF ILLUSTRATIONS APPEARING ELSEWHERE IN THIS REPORT. THEY HAVE BEEN REPRODUCED HERE BY A DIFFERENT METHOD TO PROVIDE BETTER DETAIL